



# The Architecture of Soft Machines

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in fulfilment of the requirements for the degree of  
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Supervisors: Prof Neil Spiller, Dr Marcos Cruz.

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## Statements

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Michael Wihart

April 2015

## Abstract

This thesis speculates about the possibility of softening architecture through machines. In deviating from traditional mechanical conceptions of machines based on autonomous, functional and purely operational notions, the thesis proposes to conceive of machines as corporeal media in co-constituting relationships with human bodies. As machines become corporeal (robots) and human bodies take on qualities of machines (cyborgs) the thesis investigates their relations to architecture through readings of William S. Burroughs' proto-cyborgian novel *The Soft Machine* (1961) and Georges Teyssot's essay 'Hybrid Architecture: An Environment for the Prosthetic Body' (2005) arguing for a revision of architecture's anthropocentric mandate in favour of technologically co-constituting body ideas. The conceptual shift in man-machine relations is also demonstrated by discussion of two installations shown at the Venice Biennale, Daniel Libeskind's mechanical *Three Lessons in Architecture* (1985) and Philip Beesely's responsive *Hylozoic Ground* (2010). As the purely mechanical model has been superseded by a model that incorporates digital sensing and embedded actuation, as well as soft and compliant materiality, the promise of softer, more sensitive and corporeal conceptions of technology shines onto architecture. Following Nicholas Negroponte's ambition for a 'humanism through machines,' stated in his groundbreaking work, *Soft Architecture Machines* (1975), and inspired by recent developments in the emerging field of soft robotics, I have developed a series of practical design experiments, ranging from soft mechanical hybrids to soft machines made entirely from silicone and actuated by embedded pneumatics, to speculate about architectural environments capable of interacting with humans. In a radical departure from traditional mechanical conceptions based on modalities of assembly, the design of these types of soft machines is derived from soft organisms such as molluscs (octopi, snails, jellyfish) in order to infuse them with notions of flexibility, compliance, sensitivity, passive dynamics and spatial variability. Challenging architecture's alliance with notions of permanence and monumentality, the thesis finally formulates a critique of static typologisation of space with walls, floors, columns or windows. In proposing an *embodied architecture* the thesis concludes by speculating about architecture as a capacitated, sensitive and sensual body informed by reciprocal conditioning of constituent systems, materials, morphologies and behaviours.

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M.W.



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# Introduction

Preliminaries – Context – Strategies – Methods – Chapter outline

At some point I noticed that my machines were getting softer. My machines were not always soft, but as they got softer, my thinking became more drawn to the relational, embedded and the inseparable. I noticed that I had to overcome the notion of the assembled and its ties to the mechanical – in which most of architectural practice is still trapped – in order to approximate the embodied.

A symbolic collaboration with nature informed my design strategies.

When American architect Nicholas Negroponte published *Soft Architecture Machines* in 1975 he began with a retreat from the optimism voiced in its 1970 predecessor *The Architecture Machine*. After several years of work, the idea of replacing human designers with computers was overturned by the conviction that architectural machines ‘won’t help us to design; instead, we will live in them.’<sup>1</sup> Negroponte’s quest for a ‘humanism through machines’<sup>2</sup> led him to recognize – but not resolve – the philosophical schism between intelligence and machines. In the publication prefixed with the then fashionable term ‘soft’ he noted that his inkling was that ‘soft materials and cellular pneumatics [are] the most natural materials’<sup>3</sup> to reconcile the schism. Since then the soft disruption heralded by the digital has begun to inspire an intensified engagement of the machine with organic corporeality, only to appear more recently as a new generation of soft machines made entirely from soft materials in the emerging field of soft robotics.

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<sup>1</sup> Negroponte 1975, 5.

<sup>2</sup> Negroponte 1970, x. The ideas contained in *The Architecture Machine* were first set out in the article ‘Towards a Humanism Through Machines’ in *Architectural Design*. no. 7/6. September 1969. pp 511-12 and in *Technology Review*. vol 71. no 6. April 1969.

<sup>3</sup> Negroponte 1975, preface p. ix.

Not yet realising its history, when I constructed a machine in 2004 that was activated by swelling of elastic cellular joints, I came to describe it as a ‘soft machine.’<sup>4</sup> Since then I have been following its instructions.

This research project originates from a frustration with the tendency of architectural design to default to stasis and monumentality, which is somehow paradoxical when contrasted with the dynamic conditions by which it is surrounded and which it houses. This thesis proposes alternative design strategies by letting softness permeate the architectural realm and giving it activity and sensitivity, or in a more primal sense, reciprocating human embodiment in the constructed realm of architecture. Standing against disciplinarian functions imbued in architecture, the research seeks to contribute to more inclusive ideas, with its design practices and heuristics. Not in an anthropomorphic way that abuses the human body as formal template based on abstracted and geometrical notions, but in a more generative way inspired by its experiences, capacities and sensualities. With a dedicated commitment to an anthropocentric conditioning of architecture,<sup>5</sup> I have developed thoughts and theories through experimental design, making and critical reflection. In this respect, the thesis does not only speculate about reasons for the ‘softening’ of architectural machines but also proposes designing and theorizing strategies to inspire a sense of human sensitivity and corporeality within the architectural realm. The logical consequence of giving the architectural machine a body and the subsequent projection of its corporeal characteristics into the design space of architecture results in the seemingly paradoxical notion of *architecture softened by machines* – an architecture that experiences itself as embodied.

## Preliminaries

The primary aim of this research is to better understand – and integrate – architectural soft machines as experimental medium in architectural design. In its function as architectural medium the soft machine is part of an architectural design practice that

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<sup>4</sup> My then design tutor Phil Watson introduced me to the idea of a ‘soft’ machine.

<sup>5</sup> Inspired by Michel Foucault and George Teyssot reflections about anthropology in this thesis are based on the human condition in Western philosophy. This concept of anthropology does not refer to various external cultures, as Michel Foucault has made clear (Teyssot 2013, 159 and footnote 23.)

reflects about how the designed environment shapes the human condition through the application of technology. Situated in the wider landscape of technology it is part of a physical renaissance. As the translocation of human activity into the virtual realm is currently being rebalanced, autonomous physical machines are beginning to take over human activities. In the same way the digital realm has disrupted discretionary things like shopping, news and entertainment, machines are now in the process of disrupting essential human activities such as health care (social robotics, service bots), medicine (operation robots), transport (autonomous vehicles), manufacturing (automation, collaborative robotics) and construction (robots, printed and programmable materials) by becoming corporeal, taking on properties of the human body and partially replacing it. But these developments are not led by a resurrection of the machine in a conquest against nature. Instead designers are appealing to the higher orders of the living realm.

The encounter of the machine with softness gives rise to two basic assertions. On the one hand, the *confrontation* of the machine with softness asks the machine: ‘Why are you only hard?’ and it must admit that it is a tool against nature. On the other hand, the *alliance* of the machine with softness inspires collaboration with nature, in an attempt to dissolve the opposition between the organic and the artificial, and learn from her.

### *Softness*

Speculations about the encounter of the machine and softness – not only through control by *software* protocols but also materially – can further the design of architectural machines. In the biological realm, softness is a fundamental requirement for bodies capable of motion, which in turn has to be controlled through a nervous system and a brain. Evidence in research of biological mental development, Embodied Intelligence (EI) and robotics suggests that an active, soft body is indispensable for the acquisition of artificial intelligence.<sup>6</sup> Soft robotics researchers, such as Rolf Pfeifer, director of the Artificial Intelligence Laboratory at the University of Zürich, maintain that there is a limit to how well hard-bodied systems can replicate sensitivity, motility, self-awareness and adaptation (of themselves as well as of their environment). They argue that morpho-

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<sup>6</sup> Pfeifer and Josh 2007; Pfeifer, Lungarella and Iida 2007.

neurogenetic integration of softness into artificial systems will lead to new types of machines that will enable seamless interactions.<sup>7</sup>

In architecture the causal relation of soft corporeality and intelligence has also been recognized by several authors as a design imperative for speculations about buildings capable of motion.<sup>8</sup> Sociologist Elda Danese has observed that ‘softness, not considered metaphorically, ... defines the present technological tendency towards the use of flexible, light and elastic materials.’<sup>9</sup> Danese maintains that this development represents a radical disruption in machine design, potentially heralding ‘a new appearance of machines and technology.’<sup>10</sup> Softness is normally associated with passivity, and its activation through machination poses novel design and engineering challenges. In addition, characteristics of soft materials and components, such as compliance (due to their softness they cannot harm humans) and passive dynamics (instead of resisting, passive or under-actuated parts can passively take part in movements) are central strategies for soft machinic design.

This thesis assumes that three ongoing developments are contributing to the softening of machines. The first is driven by the alignment of human creation with that of nature through biophile design strategies.<sup>11</sup> The second development is the conjunction of machines and embodied strategies driven by artificial and embodied intelligence research. The third development is driven by advances in material technologies leading to tuneable and programmable materials with adjustable or active behaviours. Based on these assumptions, my research hinges on the hypothesis that soft machines are contributing to a paradigm shift in the machine continuum towards softer, more embodied and situated conditions.

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<sup>7</sup> Pfeifer and Josh 2007.

<sup>8</sup> Oosterhuis 2002, Palumbo 2000.

<sup>9</sup> Danese 2003, 268.

<sup>10</sup> Danese 2003, 268.

<sup>11</sup> The term ‘biophile’ suggests an instinctive and archetypical bond between human beings and other living systems. This hypothesis has been popularized by the American biologist and theorist Edward O. Wilson in his book *Biophilia* (1984). Although Wilson did not mention it in this book this concept has been introduced

## *Soft machines*

In my own work I use soft machines as experimental medium. Soft machines are not architecture in terms of buildings per se, but they are tools to speculate about certain conditions related to the human use of architecture. In similar ways to a drawing, a section, an algorithm or a model, they investigate certain aspects of architecture. They are informed by an anthropocentric mandate but are not anthropomorphic. As medium of architectural design I propose soft machines as bio-inspired tools, enabling speculation about the centrality of the human condition in designing architecture.

However, the term ‘soft machine’ is used in different fields and therefore it is necessary to clarify its meaning in the context of this thesis. When the American writer William S. Burroughs published his second novel titled *The Soft Machine* in 1961, readers were left to their own speculative devices to define what the soft machine actually was, as Burroughs nowhere mentions the term.<sup>12</sup> Hustled by his British publisher, Burroughs added an appendix to the 1968 edition<sup>13</sup> in which he explained that ‘the soft machine is the human body under constant siege from a vast hungry host of parasites.’<sup>14</sup> In his work Burroughs conjured up proto-cyborgian dystopia where prosthetics, artificial body parts, and invasive technologies exert increasing influence on human behaviour. Opening up an important field where the term ‘soft machine’ signifies the entanglement of the human body with machines, Burroughs insinuated the notion that in order to be able to invade/ extend/ repair the body, technology must become like the body. The notion of the technologized body has subsequently become a dominant denominator of the human body as cyborg, described in 1985 by Donna Haraway as ‘fabricated hybrids of machine and organism,’<sup>15</sup> and exemplified in exhibitions such as Marie O’Mahony’s ‘Soft Machine – Design in the Cyborg Age’ at the Stedelijk Museum in 1998 or Elsa Danese’s essay ‘Soft Machines.’<sup>16</sup> In

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in 1964 by the German-American social psychologist and philosopher Erich Fromm in his book *The Heart of Man*, where Fromm describes man’s instinctive and psychological orientation to all that is alive and vital.

<sup>12</sup> Porush 1985, 101.

<sup>13</sup> The 1968 British edition has been extensively reworked by Burroughs to give a more traditional structure plus the addition of new material. The appendix was included in no other edition.

<sup>14</sup> Burroughs 1968, 170.

<sup>15</sup> Haraway 1991 [1985], 150.

<sup>16</sup> Danese 2003.



more pristine and idealised ways, the human body has also been described as soft machine in the field of ergonomics.<sup>17</sup>

Research into the historical role of soft machines in human endeavours to simulate processes associated with living beings or the creation of artificial life would have provided ample material. Investigations of these topics were necessarily excluded due to constraints of space, and a focus on the application of the soft machine to architectural theory and design. In broadening the scope of research into the history of soft machines, studies of early precedents such as Cornelius Drebbel's (1572 - 1633) infamous incubator,<sup>18</sup> described by historian of science Otto Mayr as the first feedback device invented since antiquity,<sup>19</sup> or the French King Louis XV's midwife Mme du Coudray's (1712 - 1794) 'birthing machine,'<sup>20</sup> can potentially yield a better understanding of the techno-social and socio-cultural evolution of soft machines and their entanglement with the greater machine continuum in general. As historian of science Jessica Riskin states in her essay 'Eighteenth Century Wetware,' Mme du Coudray's birthing machine reflected the assumption that 'an artificial model of a living creature should be soft, flexible, sometimes also, and in these ways resemble its organic subjects.'<sup>21</sup> These early precedents of softer conceptions of machines carry in them the same belief that guides our appreciation of contemporary machines, devices and autonomous systems.

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<sup>17</sup> Lueder and Noro 1994.

<sup>18</sup> Drebbel's incubator was thought to have alchemic purposes following the belief that extensive heating of lesser substances could produce gold. Drebbel was a Dutch engineer and inventor, part necromancer, part experimentalist. His incubator was admired, amongst many others, by a certain young Christopher Wren, who used to be a keen student of astronomy and mechanical devices, before his second career as architect. Further reading: 'Cornelius Drebbel: Ein Kurßer Tractat von der Natur Der Elementen,' first published in 1608. In L.E. Harris, 'Cornelius Drebbel: A Neglected Genius of Seventeenth Century Technology,' *Transactions of the Newcomen Society*. vol 31 (1957), pp. 195-204.

<sup>19</sup> According to Mayr Drebbel's incubator precedes Watt's famous steam machine governor. See Mayr 1970, 127.

<sup>20</sup> Rattner Gelbart, Nina. 1998. *The King's Midwife: A History and Mystery of Madame Du Coudray*. Berkeley, Calif.; London: University of California Press.

<sup>21</sup> Riskin describes the machine to have 'many skin and soft organs made from flesh-coloured linen and leather, some dyed redder and some paler, and stuffed with padding. The earlier models were built on pelvic bones taken from real skeletons; many of the later ones used wood and wicker. As a "supplement" to the machine, one could buy "liquids," an opaque red fluid and a clear one, along with a set of sponges (2007, 258).'

More recently, the term ‘soft machine’ has begun to occur in fields such as soft robotics<sup>22,23</sup> and artificial intelligence,<sup>24</sup> material sciences and engineering,<sup>25</sup> bio-inspired engineering, chemistry<sup>26</sup> and nanotechnology.<sup>27</sup> The term is generally used to allude to the machinic nature of biological organisms, or to the bio-inspired construction and performance of artificial machines. Knowledge transfer from these disciplines is crucial for speculations about the potential of soft machines in architecture. Introducing the ‘soft machine’ to the field of architecture creates a conceptual lineage that entangles ideas of technology with ideas of the human body, promising a new machine continuum. As such, soft machines are my experimental tools in search of meaningful and embodied mediations of the human condition with architecture.

## Context

### *Machines in architecture*

Machines have been part of Western architectural discourse from Vitruvius<sup>28</sup> to Michelangelo<sup>29</sup> and have informed much of modernity’s affirmation of architecture as an ‘environment of the machine aesthetic,’<sup>30</sup> in new logics of production as well as in aesthetic expression, epitomized in Le Corbusier’s much quoted rubric ‘A house is a machine for living in.’<sup>31</sup> More contemporary coalitions range from architectural projects

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<sup>22</sup> Crespi et al. 2005, 163-175. Notable institutions that have adopted the terminology are the Soft Machine lab at Carnegie Mellon University’s founded by Carmel Majidi or the Whiteside’s Group at Harvard and the Shepherd Laboratory at Cornell University specialising research, amongst others, on soft machines.

<sup>23</sup> Iida et al. 2012, i.

<sup>24</sup> Pfeifer et al. 2012, 78.

<sup>25</sup> Keplinger et al. 2013, 984-987; Keplinger in press release of Harvard School of Engineering and Applied Sciences, ‘Transparent artificial muscle plays Grieg to prove a point’ (August 29, 2013); accessed 03/09/2013.

<sup>26</sup> See research led by George M. Whitesides, a prominent chemist who specializes in soft machines, among many other topics. Whitesides is the Professor in the Department of Chemistry and Chemical Biology, co-director of the Kavli Institute at Harvard, and a Core Faculty Member at the Wyss Institute for Biologically Inspired Engineering at Harvard. See for instance McDonald et al. 2001; Qin and et al. 2010; Ilievski 2011.

<sup>27</sup> Jones 2004.

<sup>28</sup> Vitruvius 1999, Book X.

<sup>29</sup> Wittkower 1967, 101.

<sup>30</sup> Banham 1984, 122.

<sup>31</sup> Le Corbusier 1946 [1923], 100.

designed in metaphorical allusion to machines (Denari, Cantley, Wang), buildings animated by machines or machinic components (Kundig, *Chicken Point Cabin*; Koolhaas *House Bordeaux*), machines as mythopoietic medium (Libeskind) or dynamic artefacts charged with narratives (Beesley, Glynn, Khan, Wihart). The long alliance of architecture and machines in Western culture has produced a spectrum of practices, methods and applications where machines or machine-like manifestations range from devices, apparatus to systems, installations or entire buildings.

Architecture's contemporary leaning towards the animated and dynamic<sup>32</sup> also coincides with a wider shift towards the integration of 'performance as practice,' which artist and media theorist Chris Salter postulates to become one of the major paradigms of the twenty-first century.<sup>33</sup> According to Salter, this development is marked by growing interest in issues of embodiment, situatedness, presence and materiality and coincides with the subsidence of the euphoria for the simulated and the virtual. Slater postulates a shift from *mimesis* to *kinesis*.<sup>34</sup> When applied to architecture, this shift from mimetic to kinetic thinking entails the construction of performance through technology. Dissolving modernity's great divide between nature and culture, of which Bruno Latour has reminded us,<sup>35</sup> machines can become an architectural medium with enunciative powers, in Félix Guattari's sense.<sup>36</sup> In fact, such machines may engender new forms of subjectivity, experience and forms of enquiry.

### *Machines in academia*

Machines that are purposefully and especially constructed in an attempt to better understand or challenge fundamental human conditions in relation to the design and construction of space are predominantly explored in the academic context. Dan Hoffman highlights in *Architectural Studio* (1994), an edition showcasing the Cranbrook Academy's

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<sup>32</sup> Spiller 1998; Lynn 1999; Kolarevic and Malkawi 2005; Cruz 2008; Hannah and Khan 2008. Schuhmacher et al. 2010.

<sup>33</sup> Salter 2010, xxi.

<sup>34</sup> Slater himself refers to Conquerwood 1989, 83. Mimesis (Greek: *mīmēsis*) alludes to imitation, representation, mimicry. Kinesis (Greek: *kinēsis*), in biology, is a movement or activity of a cell or an organism in response to a stimulus. In Conquerwood the transition from mimesis to kinesis alludes to a transition in performance from imitation as (re-)construction to intervention as socio-political act.

<sup>35</sup> Latour 1993.

investigation into temporality and process in architecture, that '[m]odern technology permits us to make instruments and machines that provoke these conceptual limits ... precipitating the development of new theories and forms of knowledge.'<sup>37</sup> Working with architectural machines often involves collaborative and cross-disciplinary research engaging with practices and methods of science, technology, arts, humanities or performative media. But as with the common usage of 'machine' it would be impossible to conclusively define the term 'architectural machine' due to the vast range of ideas explored and expressed through machines. Machines and devices have entered the architectural curriculum as experimental educational medium in László Moholy-Nagy's preliminary courses taught at the Bauhaus in Dessau.<sup>38</sup> This tradition has been reinforced at schools such as the Architectural Association in London in the 1960s and 70s. Throughout the 1980s and 1990s machines began to play an important role at schools such as the Cranbrook Academy of Art, Cooper Union, Bartlett School of Architecture and Southern California Institute of Architecture amongst many others. Christine Hawley and CJ Lim point out the potential of machines as design medium, reflecting that projects in their design course started with 'an exercise of invention, identity and construction' where students were to 'build machines whose working parts were to execute function,' 'the narrative of which was to form the catalyst for their proposed building ...'<sup>39</sup> With the availability of affordable computing, sensing and actuation devices, rapid prototyping and a vast range of materials, a renaissance of architectural machines heralded experimentation with concepts such as responsiveness, adaptability and interaction.<sup>40</sup> As technology moved from the background into foreground, machines equipped with sensors, actuators, and computational control units, began to create new relations between human beings and architecture: a development that can be observed by comparison of two prominent machine exhibitions shown at the Venice Biennale. Daniel Libeskind's *Three Lessons in Architecture* (1985), discussed in chapter 1, and Philip Beesley's *Hylozoic Ground* (2010), discussed in chapter 2, demonstrate the conversion of architectural machines from stand-

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<sup>36</sup> Guattari 1995, 34.

<sup>37</sup> Hoffman 1994, 11.

<sup>38</sup> Moholy-Nagy 1947, 21.

<sup>39</sup> Hawley and Lim 1995, 15.

<sup>40</sup> Haque 2006.

alone mechanical entities to hybridized networks of machinic assemblies seeking inter-corporeal exchange.

### *Architectural media*

Architectural machines tend to carry strategies for the architectural appropriation of technology. As soft machines are embedded in the wider debate about the role of architectural machines, they are – like the drawing or the model – used as an architectural method for developing, testing and communicating ideas. While drawings or models can mainly *represent* ideas in non-dynamic media, machines allow the *embodiment* of ideas in dynamic media. And unlike the drawing or the model, which are characterised by an abstracted or scaled expression of a proposed idea, the architectural machine expresses and engenders inherently physical characteristics and interaction due to its physicality, corporeal appearance and performance.<sup>41</sup>

At this point I also want to highlight that I have drawn on more general discussions of the role of machines and adapted these for discussions of the role of architectural machines as architectural media. Félix Guattari highlights in his text ‘Machinic Heterogenesis’ that machines tend to be positioned as a ‘prerequisite for technology.’<sup>42</sup> Guattari maintains that ‘[w]e should, however, consider the problematic of technology as dependent on machines, and not the inverse.’<sup>43</sup> While architectural machines are technological beings that have been created from ideas of this world, we also induce in them fantasies and speculations that take them beyond the possibilities of this world. Francois Roche from architectural practice R&Sic<sup>(n)</sup> and robot designer Stephan Hinrichs indicate the inspirational potential of machines thus:

Machines are always pretending to do more than what they were programmed to do. It’s their nature. Their behaviour induces in us phantasms, frustrations, and fears inspired by their ability to break free and threaten us (as the Golem did to its creator, Rabbi Loeb). The blurriness between what they are supposed to do – as perfect, alienated,

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<sup>41</sup> Gage 1998.

<sup>42</sup> Guattari 1995, 33.

<sup>43</sup> Guattari 1995, 33.

and domesticated creatures – and the anthropomorphic psychology we intentionally project on them creates a spectrum of potentiality – both interpretative and productive – that is able to re-scenarize the operating process of the architectural field.<sup>44</sup>

Machines are manifestations of humankind's long-standing fascination with the transcendence of inert matter by means of technology. In similar ways, soft machines pretend to do more than what they are designed to do. Physically they might be material and mechanical but their functions and enunctiative capacities project them beyond the realm of technology. Soft machines carry in them an inherent capacity to imbue architectural thinking with ideas of softness, corporeality and sensitivity. They allow designers to project human behavioural characteristics into the spatial realm by conceiving and analysing architecture through machines that have a soft body.

## Strategies

In an attempt to inspire architecture with a renewed anthropocentrism based on the appreciation of the human as embodied being, rather than an abstracted, formalised, geometric template, soft machines are discussed as means for the self-cultivation of the architectural mind. This approach applies Bruce Mazlish's notion of the co-evolution of humans and machines<sup>45</sup> and Elisabeth Grosz's notion of the human production of itself as a species through self-cultivation of minds and bodies<sup>46</sup> to the use of machines as architectural media. As such architectural machines are positioned in this thesis not as stand-alone technological artefacts, but as integral and co-constituting agents in human self-reflection, action and behaviour. In his book *A Thousand Machines* (2010), Gerald Raunig emphasizes that a machine only becomes relevant to human existence when its connections to human beings are appreciated. Without these connections a machine might be a solitary and unconnected entity.

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<sup>44</sup> Corbellini 2008, 11.

<sup>45</sup> Mazlish 1993, 3.

<sup>46</sup> Grosz 2006, 188. Grosz's notion itself is an interpretation of Nietzschean thought.

Is it about a machine? The question is not easy to answer, but correctly posed. The question should certainly not be: What is a machine? ... It is not a question of the essence, but of the event, not about *is*, but about *and*, about concatenations and connections, compositions and movements that constitute a machine. Therefore it is not a matter of saying “the bicycle *is* ...” a machine, for instance, but rather the bicycle *and* the person riding it, ... , the bicycles *and* the bicycle thieves, etc.<sup>47</sup>



fig 0.01 Alfred Jarry (1873-1907) on a bicycle.

Without the rider the bicycle would be but a mere object. It is only through the connection of the limp metallic frame with the human body that the bicycle awakes to being a bio-mechanical hybrid, which reflects a new image of the body as well as of the machine. The human being is capacitated to discover new modalities of perception and overcomes bodily limitations through intimate connections with the machine. Whether operation is remote or through direct interaction, the bond between the human being is the live thread, the umbilical cord for the machine. I argue that the connection of human beings with architectural machines should be understood in a similar sense. In paraphrasing Raunig's observation of the machine, the question should not be: What *is* an architectural machine? The question should be about the interaction between the architectural machine *and* its creators / observers / users. Therefore it should not be a matter of describing an architectural machine as isolated technological structure, but rather describing how it creates relations and interactions with human beings.

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<sup>47</sup> Raunig 2010, 19.

### *The human body as design generator*

The intensified exchange between humans and soft machines can be projected into speculations about architecture by inspiring in machines capacities and sensitivities associated with human beings. The formulation of an architectural anthropologic that is carried through the thesis and is discussed more extensively in chapter 3 is based on technologically extended body ideas inspired by an architectural reading of Burroughs' novel *The Soft Machine* (1961). The human body is staged, not under the auspices of the classical proportional ideal or rationalization, but under the anticipation of its synthetic reflections. Soft machines, mediating their own embodied particularities within spaces shared with human beings – instead of virtual topologies evacuated of corporeal logic – seek to infuse architecture with corporeal strategies; not as an analogue of the body but as an enabling technology capacitated by conditions arising from the corporeal. In her book *New Wombs* (2000) Maria Luisa Palumbo maintains that this approach makes it essential to overcome the logical opposition between 'the *organic* universe of the body and the *mechanical* universe of technology, in a new logic of complexity in which the life of the body and forms meet through the machine.'<sup>48</sup> Palumbo speculates that following 'architecture's aspiration to *be embodied* or to acquire awareness [and activity] through electronics, an ulterior radical transformation of the machine appears to lie at the root of this possibility.'<sup>49</sup> Depicting similar tendencies, media artist and theorist Robert Pepperell summarizes the ambition of many interactive, immersive architectures:

They suggest a conception of reality in which living matter is continuous with inert matter, where complexity and simplicity co-exist, where the body permeates beyond the membrane of the skin into the space around it, where each individual element is absorbed into the structure as a whole, where the built environment is an intelligent and conscious extension of the beings that occupy it.<sup>50</sup>

As the anthropocentric mandate of architecture is challenged by the appearance of machines that are capable of partially acquiring capacities previously associated with

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<sup>48</sup> Palumbo 2000, 5 [italics in original].

<sup>49</sup> Palumbo 2000, 6 [italics in original].

<sup>50</sup> Pepperell 2010, 40.



human beings, the human being itself might not be at the centre of architectural considerations anymore, but embodied in technologies that have been inspired by human capacities and sensibilities. However, the proposal to reflect human characteristics in architecture needs to be distinguished from direct approaches such as anthropomorphism or the exclusion of the human, such as in post-human concepts. Consequently, my research is not driven by the creation of machines in the image of man, but by the creation of architectural machines as experimental media that anticipate possibilities of exchange between humans and architectural surroundings.

### *Mechanics of softness*

We are able to appreciate softness only through the haptic sense, embedded in our primal envelope. The inseparable binding between skin sensitivity and motion is instructive to the design and construction of soft machines as our corporeal encounter with the artificial is ultimately governed by the way we feel it. Necessitated by this relational logic, the sensitive and mechanical capacities of human skin are discussed as soft, generative tools for designing architecture. Characteristics of soft materials, such as their yielding under external pressure, their elasticity or flexibility, can reciprocate the corporeal mechanics of human softness in architectural machines. The use of soft materials such as rubbers, thermoplastic elastomers, polyurethanes, silicones or digital materials with adjustable softness gradients has increasingly been taking influence on the mechanical design of architectural machines. The behaviours of Omar Kahn's 'reflexive architecture machines' *Open Columns* (2007) and *Gravity Screens* (2009-10) or Philip Beesley's *Endothelium* (2008) and *Hylozoic Ground* (2011) projects are characterised by mechanical conditioning through soft materials. In my own projects and prototypes, especially *Soft Machine Dementia* (2004), *Bladder Puppets* (2009), *Raiser from the Ground* (2010), *Nemone Stuehp!* (2013) and *Robe* (2013) I have experimented with infusing machines and components with behaviours and qualities that would be difficult to be attained with a traditional mechanical setup.

### *Elastic actuations*

In order to test the potential of soft mechanical conditions in architectural machines I have articulated the *activation of softness* as engineering brief. This strategy is the

consequence of the hypothesis that machines that are completely soft and elastic may enable novel structural and spatial transformations. I have found that embedded pneumatic actuation of elastic structures is a suitable and effective means for motion induction due to the elasticity and compressibility of air, and dynamic and fluent force distribution through lightweight and flexible structures (rather than stiff and heavy, axial, single-directional or rotary elements such as motors, gears or pistons hooked up to a frame). My research also reveals that elastic pneumatic systems had been already researched in the 1960s and 1970s. These research undertakings, including experiments undertaken at Frei Otto's Institut für Leichte Flächentragwerke (IL), Sean R. Wellesley-Miller's work at MIT's Robotics Lab,<sup>51</sup> and work resulting from the cooperation of Simon Conolly and Mark Fisher, are discussed as early precedents of soft architectural machines.

Researchers in the field of soft robotics have also experimented with entirely new motion induction strategies inspired by these and similar biological systems, and soft robotics concepts and enabling technologies have provided an understanding of embodiment concepts and enabling technologies for soft machine design. I have applied insights and inspirations gained from these studies to practical design, construction and experimentation with soft machines in my attempts to shape the encounter with humans in a more compliant, human-friendly way, so that the artificial attempts to approach the human on its own terms. Subsequently, I have come to propose the theory of *Pneumorphology* as an experimental framework for the bio-inspired adaptation of the hydrostatic principle for the development of pneumatically actuated, dynamically transformable structures.

The application of pneumorphology to more complex designs presents the opportunity to speculate about their space-making potential. Under the umbrella term 'morphodynamic transformations' I examine in detail how particular spatial transformations may be choreographed involving multiple pneumatic fields, cavity design and layout, elastomer specification and conditioning and phased actuation. This may lead to dynamic transformation, potentially involving highly dexterous spatial transformations, such as higher degrees of freedom (DOFs), capability of elongation as well as multiple direction bending and spatially distributed stiffness.

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<sup>51</sup> Negroponte refers to Wellesley-Miller's work as promising enabling technology.

### *Plural space of stuelping*

The elastic actuations of pneumorphology can facilitate the complete and reversible inversion of a surface, such as performed when turning a flexible enclosure such as a sock or a pocket inside out. In order to describe this process I have adapted a German word to create the neologism *stuelping*.<sup>52</sup>

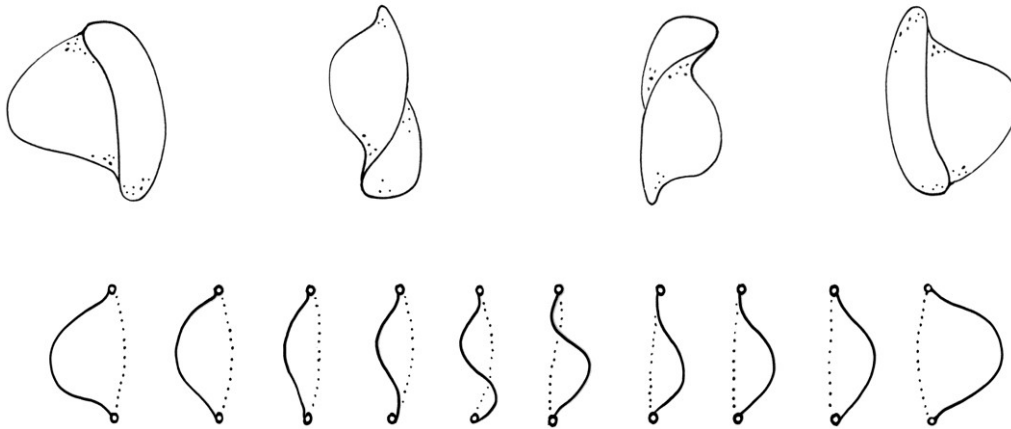


fig 0.02 Diagram for stuelping transformation.

The reversible inversion of interiority to exteriority by means of an envelope that can be turned inside out.

The stuelping of an architectural envelope is a thoroughly dynamic transformation that inverts that which has previously been inside to the outside, thus not only stuelping the envelope physically but also architecture's inside-outside duality. I have explored the spatio-dynamic potential of this reversible transformation in my studies *Broonx* (2013) and *Oasis 8 - Compliance House I* (2013 – ongoing). The thesis also applies the stuelping concept to 'projects that stuelp, but don't know it yet' such as *Balloon for Two* (1968) by Haus-Rucker-Co, *Strange Metabolism* (2007) by Mette Ramsgard Thomsen and Toni Hicks, or Omar Khan's 'softs' research, most notably *Open Columns* and *Gravity Screens* (2007-10).

## *Embodied architecture*

In the final and most speculative chapter I extrapolate the soft machine's softening potential to discussions of architectural topology and spatiality. I speculate about an embodied approach to architecture that enables designers to conceive of architecture as if it had a body so that it can learn, unlearn and accommodate human behaviour and environmental changes.<sup>53</sup> Although the emergence of ideas of embodiment can be traced back to pre-Socratic thinking – and can be found throughout the history of philosophy – concepts of embodiment have been explored with surging interest in recent years in cognitive sciences, psychology and neurosciences. In soft robotics, the concept of embodiment has been adapted during a major paradigm shift in the 1980s towards acknowledgment of the inseparable connections between the mind and its body.<sup>54</sup> However, beyond its trivial meaning that alludes to intelligent behaviour requiring a body, embodiment implies that the artefact can understand and control its own actions. An embodied architecture that can teach itself can safely and meaningfully adapt, respond or interact with human beings, eventually shifting towards more anthropo-/ bio-/ ecologically compliant modalities. Based on these aspirations, the concept of embodied architecture introduces into the design space of architecture notions of reciprocal conditioning of constituent systems, materials, morphologies and behaviours.

## **Methods**

As part of my research into soft machines as experimental media for architectural design I built several devices, prototypes and machines. In the following section I will explain the key methods used for their design. The main purpose for building soft machines as part of my design-led research was to entangle the theoretical project with practical projects, one influencing the other and vice versa in a reciprocal fashion. The research is therefore simultaneously informed by design driven processes<sup>55</sup> and a complementary process of

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<sup>52</sup> Germ.: stülpen/ 'ʃtylpn / tr. V. to pull / put sth. on to *or* over sth.; turn the / one's pockets inside out. The 'ü' of the German verb 'stülpen' has been changed 'ue' to better accommodate usage in the English language.

<sup>53</sup> Some concepts, methods and enabling technologies are discussed in c7. s3 Designing the embodied.

<sup>54</sup> Pfeifer and Fumiya 2004.

<sup>55</sup> Here I want to point to Ranulph Glanville's important statement that designers create knowledge by wishing to change the world, while scientists want knowledge of the world as it is (Glanville 2005, 115-26).

reflection, analysis and theorisation.<sup>56</sup> Thus, my design practice is a key contributor to the research project. As such, my research project is situated within the architectural design research tradition that is described as ‘research by design.’<sup>57</sup> Taking this approach allowed me to build up a theoretical statement that is scrutinised not only by theoretical methods but also by practical and experimental ones. Design based practices such as material specification, the selection of enabling technologies and construction methods influence the decision making processes that ultimately support or refute certain theoretical assumptions.

Although the studio-based projects are mainly concerned with improving and better understanding the potential of enabling technologies for embedded actuation in soft machines and their ramifications for tectonic studies, they are also part of my wider research into the methodological development of the soft machine in architectural design research.<sup>58</sup> The relation amongst the activity of designing, the methods involved and the study of the actual products needs to be understood as interdependent and co-constitutional. In order to examine the many hued aspects of design, it is worth looking at a proposition by the design researcher and educator Nigel Cross who suggests research into design falls into three categories. These categories are based on *people* (‘design epistemology,’ the ‘study of designerly ways of knowing’), *processes* (‘design praxiology,’ the ‘study of the practices and processes of design’) and *products* (‘design phenomenology,’ the ‘study of the form and configuration of artefacts’).<sup>59</sup> In keeping with Cross’ terminology, this section concentrates on the ‘design praxiology’ of my soft machines. The application of Cross’ taxonomy to this research project leads to the statement that soft machines embody design knowledge primarily in their existence as physical machines (*products/phenomenology*) and thus their inherent teleology for physicality has to be considered as part

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<sup>56</sup> Verbeke 2013, 150.

<sup>57</sup> The term has been developed since the mid-1990s by its best known proponents Jonathan Hill from the Bartlett School of Architecture and Leon van Schaik at RMIT University of Melbourne. See Hill 2003, van Schaik and Johnson 2011. Also see Murray Fraser’s introduction to ‘Design Research in Architecture’ for a more detailed discussion of the term’s uses and meaning, esp. p 3-5 and Verbeke’s essay ‘This is Research by Design’ in the same book (Fraser 2013).

<sup>58</sup> I believe that this research project contributes to positioning the soft machine as a method of architectural design research and in doing so it supports, in a wider sense, a higher appreciation of the epistemological contributions architectural machines can make to better understanding the practice and theory of architectural design. For a more general discussion see Jonas 2007, pp 187-206.

<sup>59</sup> Cross 1999, 6.

of how ‘designerly ways of knowing’ (*people/ epistemology*) arise from them during the process of their making. It is therefore important to examine the design methods employed, as the decisions taken during the process of designing and making the soft machines inevitably form part of the intellectual and theoretical project this thesis proposes. Consequently, it is crucial to understand that the activity of designing in my design practice is not a conversation between designers and their immaterial ideas,<sup>60</sup> but a designerly discourse where the built artefact (i.e. the soft machine) contributes to the discourse through its material, structural and corporeal requirements and expressions.<sup>61</sup>

Within the thesis I present more than ten projects, varying in scope and dimension. The discussion of their respective design methods is part of the introduction to the thesis, more detailed information on selected materials and construction processes is provided in the appendices.<sup>62</sup> The projects are discussed in a roughly chronological fashion in the relevant sections of the thesis, aligning their evolution with the theoretical argument towards softer conditions with the gradual softening of my own soft machine design sensibility. Within this method section I provide descriptions of three distinctive phases during which I developed my soft machine design methodologies. These phases are characterised by the way the soft machine design (‘design phenomenology’) is influenced by the way it is practiced (‘design praxiology’). The three groups are shown in illustration fig 0.03 below.

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<sup>60</sup> Glanville 1999, 88 and Pask 1976.

<sup>61</sup> For a discussion of some of the problems and solutions of the role of the object/ artefact in design research, see Saego and Dunne 1999.

<sup>62</sup> The research project involved the design and construction of a number of soft machines using different construction methods and a considerable amount of preparatory research into materials and production processes. The appendices provide selected information for a better understanding of the decision making processes involved during the making of the machines but also as a sort of glossary of materials and construction methods.

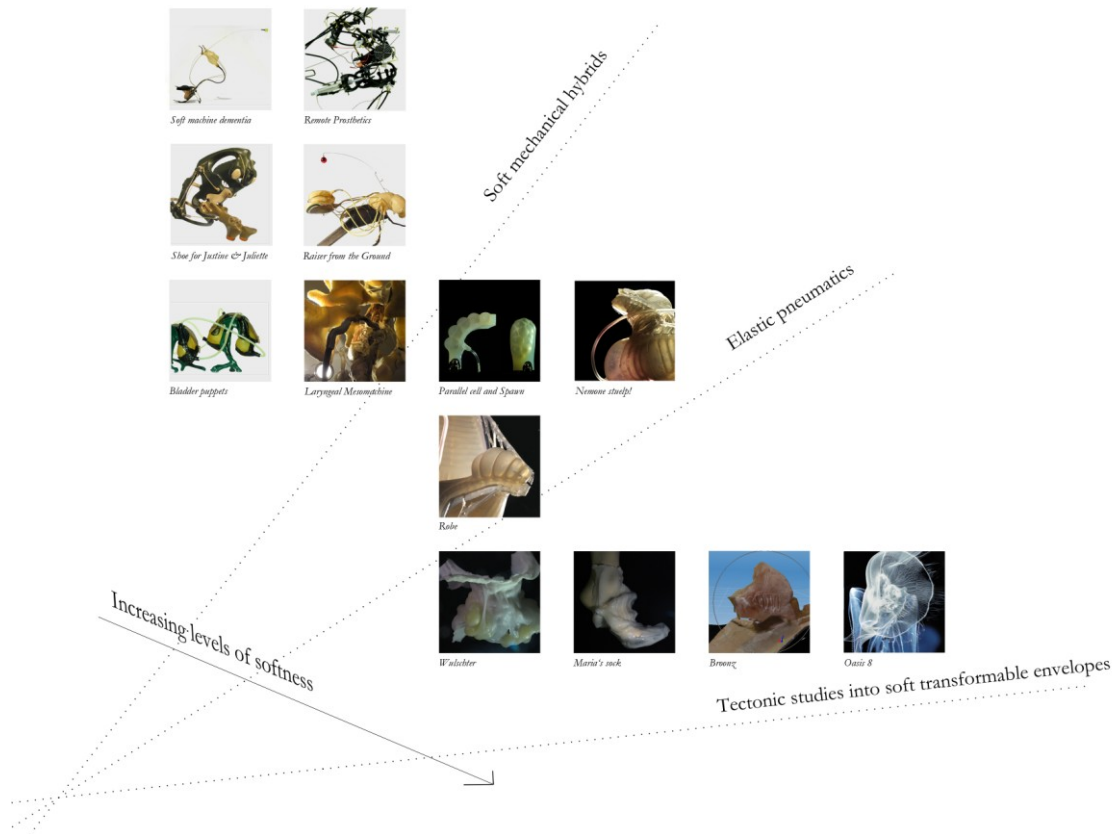


fig 0.03 Overview of my design studies.

This overview shows how the development of design is represented in the physical manifestation of the soft machine projects.

The first group, consisting of *soft mechanical hybrids*, was developed using a *design through sculpting* approach, while the second group consists of studies into *elastic pneumatics*, which were developed using a *design through elastic inflation* approach. The third group features *tectonic studies into soft transformable envelopes*. They were driven by the *design through stuepling* approach. In the following three sections, I discuss key projects as seen through the lens of the design methodologies that constituted them.

### *Design through sculpting*

The devices and machines of the *soft mechanical hybrids group* feature skeletal/ mechanical frames that are actuated by hydraulic or pneumatic components. These early projects experimented with replacing rotary components such as joints, gears and motors, which are traditionally used to drive and control machines, with non-rotary, flexible, elastic and soft components. Studies undertaken during my research have also involved the

retrospective theorisation of my first soft machines, most importantly *Soft machine dementia* (2004) and *Remote Prosthetics* (2005), which I created prior to commencing my doctoral research. They form the beginning of my interest in soft machines as experimental media for architecture and are discussed in this thesis as part of the historical development of architectural machines towards softer and more networked conditions [c2. Softer architectural machines]. These studies endeavour to compromise rigid mechanics by introducing soft components.

The design of my very first soft machine *Soft machine dementia* (2004) [fig 2.33 - 2.35] started with a sketch drawing. Based on the sketch [fig 0.04] I started making the machine's components in the workshop. However, for the design development I did not use any preparatory construction drawings or models, but instead advanced the design based on the initial design ambition.

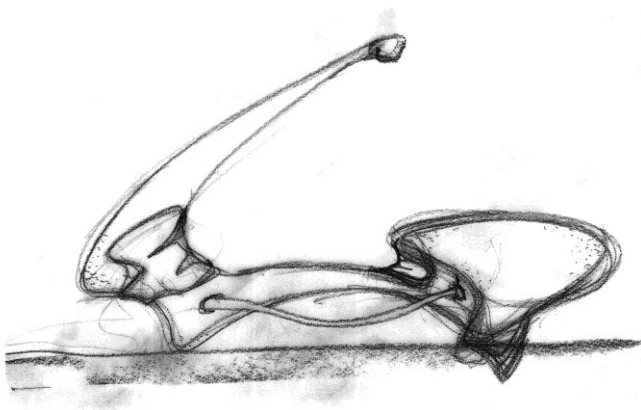


fig 0.04 Sketch drawing for *Soft Machine Dementia*

The machine was the result of my attempt to experiment with the idea that a machine might be able to ‘forget’ its movements. The methods chosen for inducing forgetfulness or ‘dementia’ in the machine were – on the one hand – the introduction of materials that are considered soft, pliable and weak. On the other hand, the mechanical layout of the machine needed to be unstable, in order to enable non-determinist/ non-repeatable movements. I made the decision to make a machine that can tip over in a seesaw-fashion. In simplified mechanical terms, the machine is a rocker with two bladders on either side. As a means of inducing motion I chose to employ the transfer of water and the harvesting



of the expansion force of swell gel. Generally, by using materials from the softer spectrum, such as brass, lead, leather and felt for the frame and vulcanised rubber, latex, water and swell-gel for the actuation components, I sought to create a mechanical configuration that is compromised by the softness of its components. Initially, the choice of materials was inspired by studying the work of Joseph Beuys and Rebecca Horn.<sup>63</sup> During the design-construction of the machine I also realised that my machine would benefit from having a name that would provide additional meaning to its purpose. Thus the machine that was designed to forget optimised, deterministic machinic ideas by infusion of softness was titled *Soft Machine Dementia*.

The machine's movements were approximated through experimentation until a satisfactory balance and location of the machine's soft components was found.<sup>64</sup> Adjusting the way the machine bends or the way the movement of the centre of gravity makes it tip over became part of the design method. The actual means of readjusting and reconfiguring the mechanical layout for *Soft Machine Dementia* was the reconfiguration of the frame, which was braced by standard hollow brass tubing. Although this choice of material allowed more efficient adjustments by cutting off or adding elements during the experimental phase, it was but a means to an end. The envisioned form of the machine frame during the design process was biomorph, as is shown in fig 0.04; due to time-constraints at the time of construction this was not pursued.<sup>65</sup> A biomorph formation of the frame was desired in order to enable a smooth, co-constituting and symbiotic integration between the soft machine's components. The standardised form of the tubing made it difficult to connect it adaptively and symbiotically to the soft and transformable shapes of the actuation bladders. The shortcomings imposed onto the design of the soft machine by its partial construction from standardised products critically informed the choice of design and construction methods for the next project.

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<sup>63</sup> Here I refer specifically to the juxtapositions of natural 'materials' in the work of Rebecca Horn, such as for instance feathers with metallic, mechanical elements (e.g. *Large Feather Wheel*, 1997) or the symbolical charging of materials with personal histories and ideas in the work of Joseph Beuys.

<sup>64</sup> The satisfactory balance was achieved when the soft machine's arm almost came to a stop mid air and then continued to bend.

<sup>65</sup> Initial ideas for constructing the soft machine's components included casts from reinforced epoxy resin and polyurethane rubber.

The project *Remote Prosthetics* (2005) [fig 2.19 - 2.24] was designed to investigate ideas of communication between machines and human beings. The project looked at the potentials of machine-human being communication through sound and motion (microphones, touch-sensitive lashes, speakers, movement) but also at machine-machine communication (hydraulic network for communication of movement patterns between machines). Thus the design methods developed for the physical components took into account the inherently dynamic condition of two machinic entities in constant exchange with each other as well as with their environment. In other words, the machines needed to be able to adapt and respond to specific input. However, in contrast to the majority of work coming from advocates of ‘adaptive’ and ‘responsive’ behaviour (e.g. Gage, Fox, Kemp, Somlai-Fischer, Haque), I sought for the adaptiveness/ responsiveness to be reflected in the materiality of architectural machines as well.<sup>66</sup> Despite a different appearance, the *Remote Prosthetics* project is highly influenced by *Soft Machine Dementia* in that for its design I strived to decrease the use of standardised components and increase the level of customisation. As a result of my critique of the frame construction for *Soft Machine Dementia* I took the decision to custom-design (and make) the frame components in a biomorph fashion.<sup>67</sup> The design of *Remote Prosthetics* was driven by an ambition for a more co-constituting and symbiotic relation between the machine’s components. However, due to the focus on custom-designing and constructing the frames, joint components, hydraulic network, microcontrollers and lash sensors, the project had to accept compromises in the form of using standard hydraulic pistons.<sup>68</sup> For the development of this project I drew construction details [fig 2.20 + 2.21], but in ways similar to *Soft Machine Dementia*, most of the components were created in iterative processes that architect and educator Bob Sheil calls ‘design through making’<sup>69</sup> using preparatory material studies, mock-ups and prototyping. The main component, called ‘cardanic joint,’ is composed of three elements. Their geometries and layout were

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<sup>66</sup> I would later find similar ambitions during my research in the work of Omar Khan, *Open Columns* (2007) or Mette Ramsgard Thomsen, *Strange Metabolisms* (2007), *Slow Furl* (2008).

<sup>67</sup> This decision was influenced after seeing Philip Beesley’s *Orpheus Filter* project at The Building Centre Trust, London, which reinforced my belief in the necessity of custom-designing components for adaptable or responsive architectural machines (Sheil 2005, 46-53). In similar terms to *Orpheus Filter* I have employed biomorph aesthetics as a metaphor for more integrated and symbiotic conditions.

<sup>68</sup> In a peculiar twist, *Remote Prosthetics* is the reverse of *Soft Machine Dementia* when comparing the relation between frame and actuating components.

constructed by hand drawings as derivations of a cardan joint.<sup>70</sup> This type of joint essentially is mechanically passive but by integrating two hydraulic pistons I activated it so that it can be used to manoeuvre objects three-dimensionally in space.<sup>71</sup> By combining multiple cardanic joints I aimed to create a machine with higher degrees of movement.<sup>72</sup> The pistons were then connected via the hydraulic network through which the movements of the machines can be induced. I chose to place the hydraulic pistons perpendicular to each other so that they can induce rotational movement around local x- and y-axis respectively. The joint elements were then sculpted in relation to the stroke length of the pistons. In ways similar to *Soft Machine Dementia* the main elements were made using sculpting and casting methods employing various coloured epoxy resins, GFP and polyurethane mixtures.



fig 0.05 [Left] Modelling armature with internal non-structural skeleton and rods for mechanical joint alignment. [Middle] One of the three elements of the cardanic joint, sculpted and embedded in clay for the production of the mould while still being held by the armature. [Right] The clay joint released from the silicone mould in the foreground, the moulds showing the negative of the sculpted cardanic joint element in the background.

For the sculpting of the matrices I used an additive technique to build the ‘anatomy’ of the joint elements based on the mechanical layout determined by the construction

<sup>69</sup> Sheil 2005, 5-12.

<sup>70</sup> A cardan joint, sometimes called gimbal, consists of two or three rings mounted in such a fashion that the innermost ring remains stable and independent of the rotation of its support rings.

<sup>71</sup> This approach was inspired by research into hybrid robotics and more specifically hexapod robot actuation, a six-degree-of freedom parallel-kinematics positioning system. See Rehsteiner, F., et al. "Putting parallel kinematics machines (PKM) to productive work." *CIRP Annals-Manufacturing Technology* 48.1 (1999): 345-350.

<sup>72</sup> During the design of the cardanic joint elements I considered servos or stepper motors as actuators, but opted for hydraulic actuation considering the momentum created in the joint connections when multiple joints were combined.

drawings. The use of oil based sculpting clay allowed me to integrate with each other various conditions such as assumed structural conditions, rotation angles of the joints and physical dimensions. In a more specific adaptation of Sheil's term 'design through making' to my own design methods, I describe the designerly creation of the cardanic joint elements as 'design through sculpting.' Developing the design using a crafting technique, such as sculpting, brings the act of designing (design praxiology) closer to the act of observing the actual product (design phenomenology), thus possibly allowing more direct and uninterrupted ways of experiencing and understanding (design epistemology) the gestation of the design into a physical artefact. The entire process from design to construction was analogue. Digital modelling techniques might have led to different outcomes.<sup>73</sup> The decisive shift in my design was towards higher levels of custom-design.

For the next series of projects, *Shoe for Justine et Juliette* (2007), *Raiser from the Ground* (2010) and *Bladder Puppets* (2010) I used similar design methods as described above. In these projects, the redistribution of weight as a means of motion induction was still an issue and was studied by sketch drawings [fig 3.15; 5.31-5.33] and preparatory material studies. However, following these initial outline designs the setting out and detailing of frames and components was developed by 'design through sculpting.' Although slightly different in its outcome, the project *Laryngeal mesomachine* (2011) was also developed based on an ambition to symbiotically integrate soft actuation into architectural machines, using the same design methodologies. The significant difference is the project's ambition to formulate a tectonic set of inquiries by creating an assemblage of envelopes that can change their shape and through this formulate varying spatial conditions.<sup>74</sup> For this project, tree roots were collected from a fallen tree.<sup>75</sup> They symbolise the 'ground' but also, due to their twisted nature, present a physically challenging building site. The root topology thus constitutes the design restraints for the envelope assemblage, which is then physically connected to selected connection sites on the roots via specifically designed intermediary structures that communicate structurally and topologically between the root

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<sup>73</sup> I have used digital methods in later studies and will discuss their influence in the next section.

<sup>74</sup> This is the reason why the project is presented in the final chapter of the thesis.

<sup>75</sup> The tree stood at the bank of the river Thames in Hartslock Wood, close to Witchurch-on-Thames, where I have discovered its upturned roots on a hiking trip in summer 2010. However, my personal history

and the transformable soft tectonic envelopes [fig 7.23]. The project was driven by the vision that the soft structures made out of polyurethane foam form the positive matrices for transformable envelopes with embedded motion induction systems driven by pneumatics. As such I endeavoured to design the actuators and also the pumps and valves in a soft and compliant manner, so that they become integrated with the entire structure. The human larynx thus was a suitable role model. Inspired by the form and function of the human larynx, the foam elements and supporting brackets were (again) designed without construction drawings, by sculpting them directly onto the roots. However, I stopped working on this project in 2012 as I did not find a satisfactory enabling technology that could be embedded into the envelopes. External motion induction, as employed in the work of Omar Khan, i.e. *Open Columns*, was not deemed suitable as it established a duality between the actuator and the actuated structure.<sup>76</sup> My mission was to overcome this duality by searching for embedded and homogeneous solutions. Research into soft robotics, undertaken later, then yielded possibilities to activate the envelopes with embedded elastic pneumatics. Thus, the *Laryngeal mesomachine* was the least successful project in terms of synthesising the design with its ambition through application/appropriation of technology, however it was the project that enabled me to overcome my object-based modality of inquiry. The project enabled me to move into a tectonic set of enquiries and formulate the speculative notions of what I would later come to describe as ‘morphodynamic primitives.’ The project also – and most importantly for the progression of my design studies – generated a structural and conceptual critique of my earlier soft mechanical hybrids.

The soft mechanical hybrids group projects allowed me to refine methods and processes, but they also highlighted the limitations of the design through sculpting approach. A critical analysis of these projects identified four main reasons: the actuator/ frame duality; the assembly of industrial mass products, standard components, etc; the design through sculpting approach; the object based inquiry. The critique resulted in a change of my

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of the tree roots bear no influence on the development of the project and are therefore not discussed further.

<sup>76</sup> At the time of working on the project I considered using EAPs (Electro-Activated-Polymers) but despite their impressive transformational capacities EAPs only exert only relatively small forces.

conception of soft machines, shifting from mechanical hybrids towards synthesised and homogenous bodies. This shift subsequently informed the research outlook for actuation technologies that favoured embedded solutions. New approaches however require abandoning established ones. I was thus led to understand that my established design methodology (that was so dependent on opportunities offered during the process of making) had to make way for new design methods that favoured higher levels of control and synthetisation.

### *Design through elastic inflation*

Following my critique of the soft-mechanical hybrids, I attempted to resolve their design limitations. The constitutional aim for softer machines motivated the dissolution of the frame-actuator/ skeleton-muscle duality in favour of a synthesised conception of structure and actuating components. The next generation of soft machines became more homogenous in materiality and was composed of integrated and embedded systems. This group of soft machine experiments was made up of prototype studies that are based largely on actuation technologies adapted from the field of soft robotics. They were made entirely of silicone. The uncompleted project *Laryngeal mesomachine*, discussed in the previous section, also made me aware that it is difficult to find a successful resolution of the soft actuation problem by designing the entire system without having resolved its constituting components. Consequently, I took a step back from the ambition to design an entire project, shifting my focus instead on the resolution of the actuation problem. I had to isolate the problem from my own design intuition and thus started researching design solutions in fields that had a comparable interest in actuation design, such as mechanical engineering and robotics, with a focus on solutions that used soft and elastic materials. As an emerging field within robotics, soft robotics has become an increasingly relevant field of research and innovation. The intriguing aspect of soft robotics is its ambition for the synthetisation of the bodily basis of natural capacities and behaviours.<sup>77</sup> Some of the challenges in the design and control of robots are thought by some soft robotics researchers such as Rolf Pfeifer, Max Lungarella and Fumiya Iida to be solvable

only by employing bio-inspired designs for soft actuation systems.<sup>78</sup> Following extensive studies of design and construction methods developed in this field [c6. s1 Soft robotics and elastic actuations] I started devising experiments based on pneumatically actuated silicone composite structures capable of changing shape [c6. s2 Pneumorphology]. I began to conceive of elastic actuation structures no longer as systematically isolated, but as embedded and networked cellular arrangements. The conceptual shift from isolated pulvinus joints to networked actuation structures initiated the conception of a new series of soft machinic elements as composite structures.

These developments, which initiated some of the most significant shifts in my research, enabled me to emancipate the design and creation of soft actuation structures from my design through sculpting approach. This shift involved a change in methodology from crafting soft mechanical hybrids married to conceptual thinking, to creating them as series of prototypes using digital modelling and fabrication for material tests and experimentation. The first prototypes, such as *Parallel cell pneumorph 5.A13* [fig 6.15] or *Spawn pneumorph Sp.A13*. [fig 6.20] were created using a lost wax casting technique.

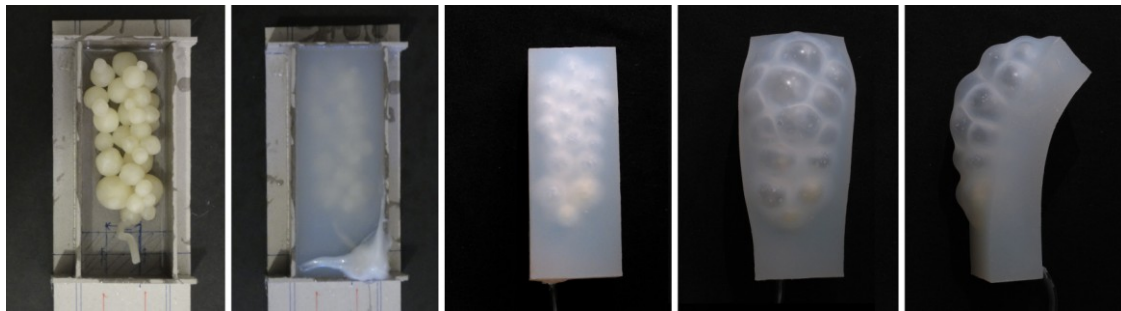


fig 0.06 Design and construction sequence of elastic silicone pneumorph prototype *Spawn pneumorph Sp.A13*. Wax matrix, silicone cast, silicone cast after evacuation of wax, front view in atmospheric pressure and side view with inflation pressure inducing bending motion. Uniform material cast with sponge-type cavities, constructed from two part addition cured silicone rubber (Shore A hardness 13).

The cavities were first built from wax elements which were packed into a box shaped mould. This mould was then filled up with silicone. Upon curing the mould was placed in

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<sup>77</sup> While these ambitions are comparable to efforts in Artificial Intelligence (AI), the distinguishing element of soft robotics is the belief that the use of soft materials can reduce computation efforts and so lead to more effective and robust models (Pfeifer and Josh 2007; Pfeifer, Lungarella and Iida 2007).

<sup>78</sup> Pfeifer, et al. 2012, 76-87.

an oven to evacuate the wax by melting it. The hollow elastic silicone container created could thus be inflated; its transformational characteristics, such as its bending curvature was determined by pressure and the geometry and properties of the silicone. The distribution, configuration and size of the internal pneumatic cavity network, as well as the thickness of the outer silicone shell and its properties determined the resulting pneumorph transformation. Through iterative testing the construction techniques were developed and findings were subsequently fed back into the design, leading to improvements of the design methods themselves.

Further analysis of these early prototypes established that in order to gain better control as a designer over the end product it was necessary to improve the construction quality and complexity. This improvement was achieved by 3D printing the moulds, which in turn allowed casting individual components that were subsequently assembled into complete silicone composites.<sup>79</sup> The first moulds were printed with nylon-based additive manufacturing techniques. Due to the porous texture of the mould, the cast was damaged beyond repair during de-moulding. Higher densities of the mould were achieved by using a VeroClear compound on an Objet Connex 500 printer. The resultant mould was ‘water-tight’ and could be used successfully and repeatedly to cast the silicone components for the pneumorph prototypes. In addition to improving the fabrication of the moulds’ physical properties such as their elasticity, Shore hardness and elongation rates have to be taken into consideration during design and fabrication.<sup>80</sup> These properties can be adjusted to a degree during the fabrication process, because silicone is an addition-cured material that solidifies into its final, soft and elastic state through catalysation.<sup>81</sup> These properties

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<sup>79</sup> This process is inspired by fabrication processes used in soft robotics. See Correll et al. 2010 and Ilievski 2011, 1890.

<sup>80</sup> For details see c6.s2 Pneumorphology, paragraph ‘Composition, structure and restraint.’ In order to further explore the potential of elastic material composites for soft machine actuation, physical aspects such as material properties and actuation performance need to be integrated into the computational design process. These developments could not be implemented in the course of the present research but are anticipated in subsequent research activities [Potential strategies and methods are outlined in c7. s3 Designing the embodied].

<sup>81</sup> The silicones used for the pneumorph experiments are condensation cure silicones. Typically two liquid components are mixed in order to start the catalysation process. Properties of the cured silicone component, such as elasticity, softness, elongation rates and colour can be pre-set by the chemical composition of the liquids, but can be changed with different admixtures. See appendix 2, material glossary for more details on silicone.



make silicone a perfectly suitable material for casting pneumorph components.<sup>82</sup> The liquidness of silicone therefore effectively influences the design and fabrication process – from digital modelling, 3D printing of moulds, casting to composite assembly. One specific aspect concerns the circumstance that silicone composite pneumorphs can only be successfully assembled before the silicone has cured fully. As a consequence the components have to be assembled as soon as the silicone has become firm enough to be de-moulded but while it is still in its curing phase. I describe this technique as ‘wet-in-wet-assembly.’ The design of the silicone composites necessitates thoroughly choreographed fabrication sequences taking into account the synchronisation of the curing times of different silicones. The final build is a thoroughly bonded silicone composite with embedded pneumatic networks made up of various cast components.



fig 0.07 Design and construction sequence of pneumorph prototype *Nemone Stuehl*!. Digital model of assembled silicone composite, 3D printed mould for cavity component, silicone cast of cavity component.

Through these refinements of my design methods I was able to increase the level of control and precision of the silicone composite assembly, which in turn led to a better understanding of the reciprocal relations of the constituent factors of pneumorphic design and construction, such as cavity layout, layer and wall thickness, dimensions of air intakes and outlets, air pressure and silicone properties. The shift in my design methods from hand sculpting to digital modelling coincides with a conceptual shift of no longer conceiving soft architectural machines as being constructed through the assembly of pre-fabricated components, but as constructing them as entirely custom-made material

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<sup>82</sup> The fabrication of pneumorph components is comparable to other casting processes used in building construction, where the solidification of liquid materials (concrete, steel, glass, plastics) takes fundamental

assemblies and composites through digital design and fabrication methods. My own design development can be contextualised with ambitions in the architectural design community towards more integrated and empirical models that take advantage of digital methods, such as 3D modelling, analysis and fabrication.<sup>83</sup> Whilst my initial concern was that I would lose the immediacy of feedback during the design process I favoured in the design through sculpting approach I came to realise that by using digital fabrication the processes of making artefacts and designing them became inseparable. Bob Sheil describes the interdependency of the design process and the construction of the final artefact as ‘a connected circumstance rather than a negotiable one.’<sup>84</sup> Sheil expands on this connection when he writes that ‘[d]esigners, conventionally the makers of drawings and models, have in their grasp the opportunity to relocate to the centre of building production with a powerful array of tools to convey innovative propositions that are fused with the information to make them.’<sup>85</sup> I find Sheil’s observation very useful in relation to the production of the pneumorph composites. The digital drawings anticipated directly their physical realisation. For the design of the next series of pneumorph studies, I used digital design and rapid prototyping, downstream processing of masters for moulding the silicone components which were built for the experiments of pneumorphic space-making. The design methods used for the studies *Nemone Stuehl!* and *Robe* (2013) embodied the knowledge and insights gained from the prototype series. In comparison to the prototypes, the design challenge was adding multiple pneumatic fields into pneumorphic envelopes and placing them opposite to each other in antagonist fashion in order to facilitate more complex and variable spatial conditions. They were developed for experimentation with the transformational potential of pneumorph structures.<sup>86</sup> The transformation of parallel cell arrangements, for example, created an active bend in one direction upon inflation. When the pressure was released, the pneumorph returned to its start position due to the elasticity of the silicone. Subsequent developments with *Nemone*

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influence on the production of the components they constitute (float glass, injection moulding, etc.).

<sup>83</sup> For a discussion of the generative integration of soft materials in the design process see my case studies of the work of Omar Kahn (*Open Columns*, 2007), Lars Spuybroek (*Soft Office*, 2001), and others [c5. s2 Incorporating the mechanics of softness into architectural design].

For practical application of this approach see for example Galjaard 2014.

<sup>84</sup> Sheil 2005, 11.

<sup>85</sup> Sheil 2005, 11.

<sup>86</sup> Specific information on construction methodologies and materials is provided in appendices 1 and 2.

*stuehl*! and *Robe* experimented with bending pneumorphs in both directions. Socalled ‘antagonistic design’ can be facilitated by placing two cavity layers on either side of a restraining layer [fig 6.25-6.27].



fig 0.08 Inflation sequence of elastic antagonist silicone pneumorph envelope of *Robe*  
 Side view with alternating pressurisation to induce bending motion in both directions.  
 Composite silicone construction with dual cavity layer separated by restraining layer.  
 Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Shore OO hardness 10)  
 Restraining layer: Two part condensation cured silicone rubber (Wacker Elastosil M4641 A/B, Shore A hardness 43).

The anticipation of the performative capacities of the pneumorphic envelopes became a fundamental influence on the design process. The feedback loop from the inflation of the pneumorph envelopes back into the design process led to an inherent understanding of the silicone body as a network of inflatable cavities. Its idle condition (under atmospheric pressure) is one of many possible conditions.

As part of my experimental research into the transformational potential of pneumorphs I also undertook desk-based research into the historical developments of elastically actuated cellular structures. The theoretical research contextualised my own design-based experimental research within the relatively young pneumatic tradition that undertook

experimental research in the 1970s in the field of transformable cellular pneumatics at institutions such as the Massachusetts Institute of Technology, the Architectural Association and Frei Otto's Institut für Leichte Flächentragwerke [c6.s3 Pneumorphic precursors in architecture] or more recently at Kas Oosterhuis' Hyperbody Research Group at Delft University [c4. s3 Pneumatic body-machine hybrids]. The design research points towards an architecture that does not use terms such as adaptability, responsiveness or compliance as rhetoric figures but actually seeks to embody them. Based on this context, the question how pneumorphic design could contribute to dynamic tectonic transformation of architectural structures emerged.

### *Design through stuepling*

Based on insights gained from the sculptural and elastic inflation approaches, I found it necessary to further explore how the transformational capacities of soft actuators can be extrapolated to the speculative design of architectural structures. For this purpose, I devised preliminary architectural studies based on the concept of morphodynamic primitives, which posits non-mechanically grounded behaviours.<sup>87</sup> These studies are discussed in the final and most speculative chapter of the thesis, where I speculate about architecture as a 'body' that is designed between human bodies and their natural or urban environments [c7 Embodied architecture]. In contrast to the earlier studies with structurally isolated pulvinus joints, the design of morphodynamic primitives, such as epithelial envelopes, stuepls, edges, apertures and folds, is based on distributed layouts of pneumorphic fields. Instead of static strictures and their mechanised openings (door, windows) this series of studies proposes a set of soft transformational typologies that reach beyond architecture's static strictures and denominations (ceiling, floor, wall, façade). These developments in my research approach, which I consider amongst the most significant in my design research, allowed me to shift from an object based inquiry into tectonic modalities. The design process was no longer focussed on the physical resolution of the pneumorphic actuation problem, but rather explored its space-making

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<sup>87</sup> A definition and discussion of morphodynamic primitives is given in c7. s1 Morphodynamic primitives, where I also point out that these primitives can be given names but due to their transformational behaviour they cannot be tied down to a fixed identity.

potential.<sup>88</sup> The transformational scenario of ‘stuelping,’ as discussed above [fig 0.02], explored the spatio-dynamic potential of morphodynamic primitives and subsequently became the tectonic leitmotif for the final series of design studies.<sup>89</sup>

The first study where morphodynamic primitives were brought together by the ‘design through stuelping’ approach is *Wulschter* (2013). I set up the study as a facade prototype to investigate how pneumorphic fields can be integrated into architectural enveloping structures. The design did not anticipate the technical resolution of the actuation problem. Instead, the study sketched morphodynamic tectonic conditions that are choreographed by different bending scenarios, field densities and varying topological configurations. The design process began by directly sculpting thixotropic silicone onto double curved forms, which I created from Wonderflex.<sup>90</sup> The low viscosity of thixotropic silicone made it the ideal material for sculptural sketching. This design method informed the form generation process with the physical properties of thixotropic silicone. Factors such as weight, viscosity and curing time took influence on the partly self-generative form finding of the silicone during its curing phase. The final design features structural formations not unlike columns [fig 7.02], skins or open containers. I did not design these features per se but seeded them by taking advantage of the slowly sagging nature of the un-cured silicone. I was able to influence the material phase transition (from un-cured to cured silicone) by mixing ratio and additives; however, during the actual form finding process I was ‘going with the flow’ while trying to maintain, loose and regain control over silicone formations that promised to be stuelpable. The final design of *Wulschter* is a photocomposition of

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<sup>88</sup> After all, pneumorphic technology presents one possible enabling soft technology while many others are currently explored in the wider field of responsive and interactive architecture. See for instance research at the Centre for Information Technology and Architecture at the Royal Danish Academy of Fine Arts, lead by Prof Mette Ramsgard Thomsen, i.e. Aurélie Mossé’s PhD research project *Self-Actuated Textiles in the Design of Domestic Spaces*, or research at the Enactive Environments group at IAD Interaction Design, Zürcher Hochschule der Künste lead by Prof Karmen Franinovic and Dino Rossi.

<sup>89</sup> Research into design methods also lead to studies of projects with similar ambitions, such as Omar Kahn’s *Open Columns* or *Strange Metabolism*, a project by Mette Ramsgard Thomsen and Toni Hicks [c7. s2 The liminal space of stuelping].

<sup>90</sup> Uncured silicone can be treated with thixotropic agents to adjust its viscosity up to a level where the silicone becomes paste-like and then can be used for application to moulds or for sculpting. Wonderflex is available in sheets and can be formed in virtually any shape in its intermediary phase when heated above 60 degrees. Upon cooling the material becomes solid again. For more information see appendix 2, material glossary.

various silicone sketches, which were sculpted separately and then merged, partly physically and partly by photomontage.

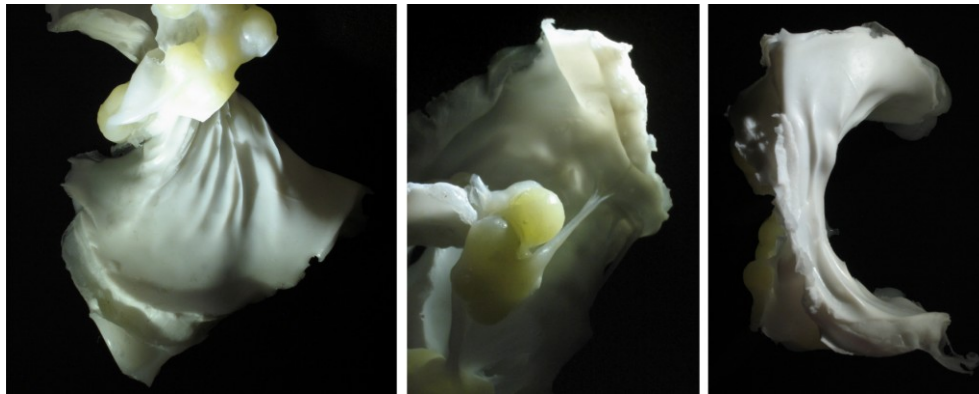


fig 0.09 Silicone sketches for *Wulschter* prior to photomontage.

Elements were sculpted separately and merged by photomontage; wax forms added into the silicone to increase or decrease the sagging effect.

While this design process was highly useful for overcoming the project's gestational threshold, I was also aware of the circumstance that the project could only evolve meaningfully if it enabled me to better understand the topological conditions of stuelpable envelopes. I therefore looked back at one basic study that investigated specifically the topological transformation of stuelping. Zooming out from the tectonic focus and looking at transformational performance, the study *Maria's Sock* [fig 7.04-7.05] basically used the form of a sock. I designed the silicone sock around a cast of a human foot so that the form could be inverted much in the same way a sock is turned inside out when pulled off the foot. From a topological point of view, a cylindrical shape is turned inside out. Considered as a soft tectonic transformation, the stuelping action presents the opportunity to examine how an architectural structure can provide spaces that dynamically create spatial conditions of seclusion or exposure. The technological resolution of stuelping, which has in this case been induced by manual folding, presents research and design opportunities involving the actuation, sensing and control of the transformation process, some of which have been anticipated by my research into pneumorphology.<sup>91</sup>

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<sup>91</sup> The concept has implications that are concerned with how a corporeal structure and its control are related to one another and to its environment. Some design and construction methods are discussed and anticipated in c7. s3 Designing the embodied.

In order to further develop my design methods for stuelpable architectural structures I started to experiment with digital design tools. I conceived *Broomz* [7.07-7.09] as a study to develop my digital design methods and *Oasis 8* [fig 7.19-7.20] as an architectural project that reflects upon the possibility of creating many spaces by means of the transformation of one envelope structure. Based on 3D scans of hand-sculpted wax geometries I composed a digitally stuelpable mesh model. The original model was sculpted in the ‘middle’ position so that once transferred into the mesh model it could be sequentially transformed into both directions to generate the start and end positions respectively. By importing the files into Z-brush<sup>92</sup> I was able to digitally transform them into sequenced positions [fig 7.08]. I also used ‘inflate’ and ‘inverse’ plug-ins in Maya<sup>93</sup> and Rhinoceros<sup>94</sup> to create more fluid transformations. For both projects, *Broomz* and *Oasis 8*, the next steps will be the design of pneumorphic actuation fields and associated control, sensing and power structures, however these steps lie beyond the scope of this thesis. Through these studies I also recognised that the manipulation of geometry alone is insufficient to understand and model the dynamic formation of stuelpable structures; additional information in the form of dynamics and behaviour indeed needs to be integrated into computational models.<sup>95</sup> However, taking this digital approach to ‘design through stueल्पing’ allowed me to conceptualise architectural functionality and expression as transitional phenomena, proposing an architectural ontology that is intrinsically non-discrete and modifiable.<sup>96</sup> The designerly description of my architectural propositions was no longer able to rely on feedback gained solely from physical models or experiments and therefore explored the digital embodiment of physical transformations.

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<sup>92</sup> ZBrush is a digital sculpting tool that combines 3D/2D modelling, texturing and painting. It was created by the company Pixologic and allows for very intuitive sculpting of the digital model with a vast range of sculpting tools and brushes.

<sup>93</sup> Maya is a 3D computer graphics software by Autodesk that is used for 3D motion animation and visual effects.

<sup>94</sup> Rhinoceros (short: Rhino) is a standalone, NURBS-based 3D modelling software.

<sup>95</sup> For relevant research into digital design of material behaviour see Oxman 2010 and for architectural contexts see Palz 2012. Some design methods and approaches are discussed in c7. s3 Designing the embodied.

<sup>96</sup> I deliberately use the term ‘expression’ instead of ‘form’ in order to enable the argument to embrace dynamic and transitional aspects of form change such as ‘stueल्पing.’ ‘Form’ might be a suitable concept to describe static architectural designs but for the description of dynamic conditions emerging from the entanglements of functionality and expression it is not.

As a designer I had to *un-train* rigid design methods (traditional tectonics, division between design and fabrication, assembly-based construction) in as much as I had to *train* soft ones (pneumorphology, morphodynamics, heterogeneous and composite material construction). The emancipation from classical architectural axioms in my design praxiology is marked not least by a search for new words and the subsequent creation of neologisms, mostly in the last and most designerly part of thesis. Naturally, this process was far from linear or continuous; it was more akin to a process of gradual disintegration on one hand and constitution on the other. But being staged in a research-by-design environment, my design practice became a generative tool for the creation of knowledge outside of its own processes. My final design studies actually not only researched the stuepling of architectural envelopes, but are physical consequences of the stuepling of my design practice (stuepling objects into spatial studies). Referring to Nigel Cross' taxonomy, my ambition to study the 'design phenomenology' of stuepling warranted a fundamental change in my 'design praxiology.' Significant developments within my design practice are often initiated by research into architectural and interdisciplinary contexts, such as Surrealism, pneumatics or soft robotics. But most importantly, they can be ascribed to the reflection upon my own design activity that produces the designs themselves; the epistemology of designing that Cross describes as the 'study of designerly ways of knowing.'



fig 0.10 Development in design practice (praxiology) and their physical manifestation (phenomenology). From left to right. a) Design through sculpting: sculpted cardanic actuators with hydraulic pistons in *Remote Prosthetics*. b) Design through elastic inflation: complete dissolution of frame/ actuator duality in favour of structurally embedded inflatable architecture in *Nemone stuepl!* c) Design through stuepling: tectonic conception of embodied architecture with stueplable structures and ancillary components in *Wulschter*.

Throughout my research I endeavoured to locate my understanding of architecture beyond the strictures of rigid mechanics. Setting up soft machine experiments as dynamic conditions enabled me to study physical qualities, performances and behaviours. One



overarching aspect of designing, physically building and testing prototypes and components was the ambition to exclude rigid mechanical approaches from the pool of possible solutions. These developments are discernible in the evolution of my soft machine design sensibility and can be exemplified by juxtaposition of typical physical manifestations of the design methods discussed above. They are shown in fig 0.09. Due to the development of my design methods throughout the research project, the design experiments enabled me to extrapolate the unique and inseparable bondage between softness and machines onto architectural design.

### *Theory*

The theories advanced in this thesis are based on critical observations and analyses of my own experiments and interpretations of similar projects, complemented by critical readings of relevant literature. Due to the inclusive, holistic and heterogeneous ambitions of the arguments put forward, my research interests range from the technical to the humanities and from the applied to the theoretical. Drawing on archival and artefactual research, this thesis seeks to inform its theoretical reflection on the contemporary role of soft architectural machines through a profound understanding of their historical precedents. Great importance is placed on the primal analysis of the theoretical pre-conditions that prevailed when architects turned to addressing or solving particular design problems by means of machines.

As the thesis examines architectural visions involving projections of corporeal capacities and sensitivities into the architectural realm, the research swerves in to fields outside the immediate periphery of architectural machine discourse, in order to inform ideas within them. This is especially the case with the sociological and philosophical discussions of human corporeality and identity in conjunction with technological extensions in chapter 3 and surrealist ideas of architecture as body, as well as the 1960s pneumatic utopian visions of architecture informed by corporeal analogies outlined in chapter 4. These historic precedents are discussed in order to provide a better grounding for the conceptual aspirations behind my propositions for an embodied architecture design theory.

## Chapter outline

Given the preliminary notes, strategies and methods just outlined, I can now describe the general structure of what lies ahead. Part 1 introduces the architectural machine as an enquiring and experimental medium, charting its mechanical origins through to contemporary attempts at superseding them. Constituting the first comprehensive history and theory of architectural machines, this part forms the prolegomena to part 2 and 3 which demonstrate the gradual emergence of a soft paradigm.

[c1] Spanning from Jean Errard de Bar-Le-Duc's extraordinary book *Le Premier Livre des Instruments Mathematiques Mechaniques* (1584) where he places the 'architectural machine' in the classic repertoires of machinery, through to Libeskind's mythopoetically charged machine trilogy *Three Lessons* shown in Venice in 1985, chapter 1 traces the historical evolution through which the machine became an explanation model for architectural design strategies.

[c2] From Wiener's *Cybernetics: or Control and Communication in the Animal and the Machine* (1948) to the bio-technological animism of architectural experimentations with bio-inspired design and responsive machine behaviour discussed by means of a case study of Philip Beesley's *Hylozoic Ground* (2010) and others, chapter 2 outlines contemporary machine manifestations by tracing convergences with computational methods and bio-inspired design strategies.

Part 2 looks at reciprocal relations between bodies and technology and their influences on 'softer' conceptions of architecture.

[c3] Chapter 3 examines theories and thoughts on symmetries between humans and machines in order to align architecture's anthropocentrism with sociological theories of technology.

[c4] Based on theories of architecture as a kind of second body, Chapter 4 looks at two distinct historical precedents of corporeal projections onto architecture – embracing human corporeality both symbiotically and morphologically (as seen in surrealism) and the promise for the animation of architecture by extending and incorporating corporeal powers (as seen in utopian and experimental pneumatics) – uncovering an anthropological binding between human beings and the transformations of elastic bodies by inspiration of air.

Part 3 speculates about notions of architecture softened by machines.

[c5] Conditioned by observations that softness of materials can only be appreciated by the sense of touch, chapter 5 turns the soft and sensitive logic of the human body on to the design and construction of soft machines with a more specific view on materials used and how they are appreciated by our sense of touch. By employing the mechanical properties of soft materials, motion induction through soft actuators and elastic joints is discussed.

[c6] Inspired by embodiment concepts and enabling technologies developed in soft robotics, I developed - through practice-led research - elastic, pneumatically actuated structures, so-called 'really soft machines.' This led to the formulation of the theory of pneumorphology. Various pneumorph prototypes are tested for their capabilities for morphodynamic transformations and space-making and the findings are discussed in chapter 6 and contextualised with historic precedents in experimental pneumatics.

[c7] Chapter 7, the final chapter of the thesis, applies the space-making potential of really soft machines to discussions of topology and spatiality, overcoming traditional spatial primitives for ordering space, such as floors, walls, and columns, in order to propose an embodied architecture composed of envelopes, edges, stueps and thresholds – spatial agencies capable of embodying the dynamic and pliable.

I conclude the thesis by outlining co-constituting and integrative design strategies for embodied research and design. Adapted from soft robotics, the embodied approach shifts architectural design away from inert strictures of tectonic strategies towards more anthropo/bio/eco/logically compliant modalities.

Within the text I provide cross-references that include in brackets the relevant chapter and section numbers of topics that have been or will be referred to in the text (e.g., [c5. s2 Design and construction with soft materials]). This simplified hypertext system is designed to establish connections and associations in conjunction with the linearity of the text.

## PART 1

# A HISTORY OF ARCHITECTURAL MACHINES



# c1 | Beyond mechanics?

Mechanics of architectural thinking – Architectural design embraces the machine –  
Imaginary potential of architectural machines

## Introduction

Architecture's long-standing alliance with machines inextricably entangled the practices of architectural thinking and design with the technological and metaphorical conditions of machines. Not only are machines indispensable for constructing or maintaining architecture. Furthermore, since early mechanical world conceptions have replaced spiritual belief systems in the Age of Enlightenment, machines and mechanics have become metaphors and motive forces in architectural design. On the one hand, machines are serving as models we employ to describe our world, including models we that we have grown from empirical evidence. On the other hand, machines are assisting us in our attempts to express our inventiveness and freedom. As ambivalent symbols and artefacts machines 'represent the paradoxes of our existence as thinking, rational, civilized beings capable of expression' as David Porush notes in his book *The Soft Machine* (1985).<sup>1</sup> Like architecture itself, architectural machines seem to exist on the threshold between the worlds of empiricism and expression.

## *Chapter overview*

A history and theory of the architectural machine as medium in architecture has yet to be written. This chapter provides the first analysis of historical architectural machine conceptions focussing on motive forces underlying the appropriation of machines as architectural medium.<sup>2</sup> Section 1 looks at the pre-conditions that have been historically present from Newton's age onwards that enabled mechanisation to become a crucial

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<sup>1</sup> Porush 1985, 13.

component of conceptual architectural thinking. The idealised autonomy and deterministic behaviour of mechanical systems provided the pretext for modernity's affirmation of the machine. Section 2 discusses how twentieth century architectural design embraced the machine as design medium, spanning from László Moholy-Nagy's educational machines which he introduced in his *Vorkurs* at the Bauhaus in Dessau to visions of machine architectures, performative buildings and living cityscapes including Archigram's architecture-as-event and the technomorph architectures of Neil Denari and Wes Jones. Section 3 looks at tactics for transcending the mechanical workings of architectural machines – Libeskind's deconstruction of architecture's epistemological standards by means of his architectural machine trilogy *Three Lessons in Architecture* shown at the Venice Biennale in 1985.

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<sup>2</sup> This and the following chapter inevitably necessitate a selection from the vast spectrum of architectural machine manifestations. A historical survey would also have to include projects of Shin Egashira, John Hejduk, Reiser + Umamoto, Diller Scofidio, Nat Chard and many others.

# s1 | Mechanics of architectural thinking

Architecture as mechanical structure – Machine-building hybrids – The mechanisation of architectural thinking

Courtesy of its physicality, architecture has always encouraged (if not required) a mechanical understanding of its spatio-dynamic particularities. With the rise of the mechanical paradigm at the beginning of the Age of Enlightenment, established by Sir Isaac Newton's mathematical interpretation of the behaviour of physical bodies, the 'body' of architecture was suddenly exposed to a mechanistic conception. It might not be surprising in this context that the machine became a dominant explanation model for architectural design strategies.<sup>3</sup> While the application of the cultural universe of Newton and the Enlightenment opened the architectural mind to the imagination of new structures and design methodologies these new strategies also undermined previous paradigms based on divine law and spiritual belief systems.<sup>4</sup> In contrast, the mechanistic conception of the world allowed architecture to break free from conventions imposed by spiritual belief systems. But the transition was everything but smooth and homogeneous, as the new world order announced by Galileo's and Newton's mechanical dominion occurred in parallel with the Baroque and Rococo movements in the arts, which stood for the expression of religious themes through direct and emotional means.

This section draws on the work of French architectural historians Alexander Tzonis and Liane Lefaivre, most notably their essays 'The Mechanical vs the Divine Body: The Rise of Modern Design Theory' (1975) and 'The Machines in Architectural Thinking' (1985), where they discuss the preconditions that have lead to the mechanisation of architectural thinking and subsequently formed the bedrock of the modern movement.<sup>5</sup> Already some

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<sup>3</sup> Tzonis and Lefaivre 1975, 4-7.

<sup>4</sup> For extensive discussion of the transformation of the decision making process in architectural design see for instance Tafuri 2006; especially chapter 1 'A Search for Paradigms: Project, Truth, Artifice.'

<sup>5</sup> For instance, Luis Fernández-Galiano draws attention to the fact that architectural historians like Giedion, Benevolo, Rykwert, Collins and Hitchcock have also situated the origins of the modern movement in this period (2000, 38).



time before the Age of the Machine the first harbingers of mechanisation would emerge, eventually introducing the inherent mechanics of machines into architectural thinking.

## Architecture as mechanical structure

According to Antoni Becchi the French mathematician, engineer and fortification architect Jean Errard de Bar-Le-Duc, in his extraordinary book *Le Premier livre des instruments mathematiques mechaniques* (1584), placed the ‘architectural machine’ [machine d’architecture] in the classic repertoires of machinery.<sup>6</sup>

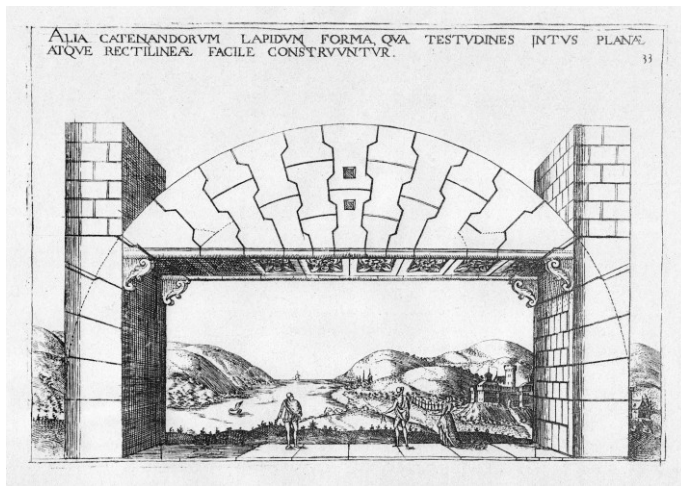


fig 1.01 Errard. Drawing of the structure of a bridge. 1584.<sup>7</sup>

Errard, in discussing the problems of structural behaviour of a bridge, raises the question of distinction between the beam and the arch.<sup>8</sup> A structural beam might be manufactured to a curvilinear geometry but it does not *ipso facto* become an arch in the true term. While the beam is monolithic in nature, the arch is constructed from individual members. This distinction might be irrelevant for the form of the arch, but is critical for the mechanical behaviour. A beam does not exert any lateral forces. The arch does exert lateral forces.

As the relations between mechanics and architecture gradually began to converge the structural behaviour of buildings was studied as mechanical problem.<sup>9</sup> Similarly, mechanical methods would be used to study the behaviour of building structures.

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<sup>6</sup> Becchi in Schlimme 2006, 106.

<sup>7</sup> Drawing by Errard de Bar-Le-Duc 1584, Tab. 33 in Errard 1584.

<sup>8</sup> Errard 1584 [1974].

<sup>9</sup> Becchi in Schlimme 2006, 98.

A couple of decades after Errard, Galileo Galilei explained in a celebrated passage of the *Seconda Giornata* of the *Discorsi e Dimostrazioni Matematiche* (1638) ‘the problem of the beam’ by converging the structural problem of the arch with the mechanics of a model that acts as an architectural machine. The passage reads as follows:

I use an exquisitely round bronze ball, no larger than a nut; this is rolled [tirata] on a metal mirror held not vertically but somewhat tilted, so that the ball in motion runs over it and presses it lightly. In moving it, it leaves a parabolic line, very thin, and smoothly traced. ... The other way to draw on the prism the line we seek is to fix two nails in a wall in a horizontal line, separated by double the width of the rectangle in which we wish to draw the semi-parabola. From these two nails hangs a fine chain, of such length that its curve [sacca] will extend over the length of the prism. This chain curves in a parabolic shape, so that if we mark points on the wall along the path of the chain, we shall have drawn a full parabola.<sup>10</sup>

As Becchi points out, when Galileo discusses the structural problem of the arch as a chain architecture becomes entangled with its mechanics and construction.<sup>11</sup> The mechanical behaviour of the chain was transferred into the architectural structure, which has already led Errard to discuss such constructions as ‘architectural machines.’ From Galileo’s description of the construction of a parabolic line by mechanical means to the classic repertoire of machines used as metaphors for architecture, the conjuncture of architecture and machines has prefigured a paradigm shift towards empirical methodologies. Alexander Tzonis and Liane Lefaivre point out that with the advent of Galileo’s mechanics the machine became an influential medium in architectural thinking.<sup>12</sup> And while machines and architecture co-existed in archaic times - prior to the establishment of mechanisation - from then onwards their structures and strategies would progressively blur.

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<sup>10</sup> See Galilei 1638 [1974], 142.

<sup>11</sup> Becchi in Schlimme 2006, 106.

## Machine-building hybrids

In pre-industrial Europe, when mechanics developed to such a degree that it could replace human labour by harvesting the force of wind or water, mechanical structures became an integral part of the architectural envelope. In the form of windmills and water mills the structure of machines became entangled with the structure of buildings.

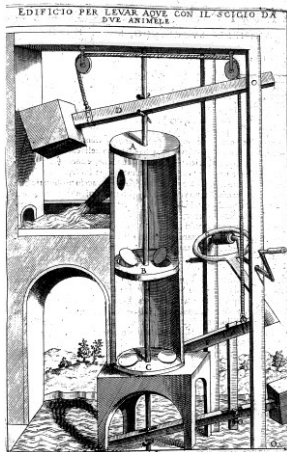


fig 1.02 Water lifting device-building hybrid in which the structures of machine and building coincide; in Vittorio Zonca. 1607. *Novo Teatro di machine et edificii*.

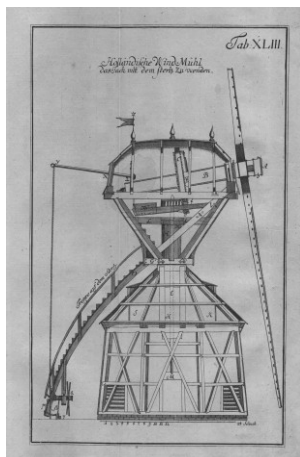


fig 1.03 Medieval windmills are an example of mediated mechanical and building technologies; in Leupold. *Medieval Windmill*. 1724. Tab XLIII. p 392.

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<sup>12</sup> Tzonis and Lefaivre 1985.

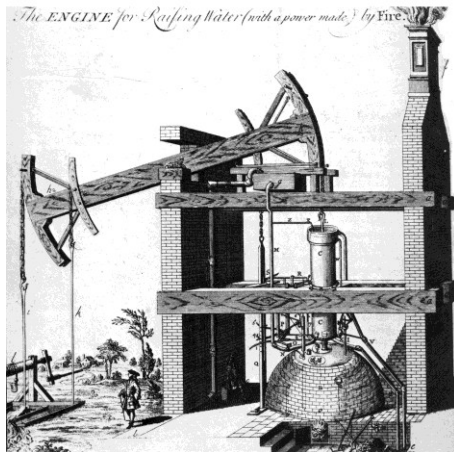


fig 1.04 Newcomen steam engine. 1712.

Original title 'Engine for raising water (with a power made) by Fire.' The building is a structural framework for machine. Newcomen manufactured his first steam engine for the Coalbrookdale Company.

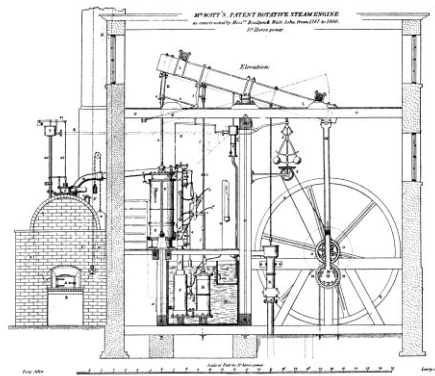


fig 1.05 Patent drawing of Watt's patent rotary steam engine. 1787. A compact and self-regulating engine, structurally uncoupled from building.

The entangled co-existence of buildings and machines coincided with the beginning of the era of feedback control for the self-regulation of machines, when in 1784 the first double-acting rotative engine was erected by Boulton & Watt at the Albion Mills at Blackfriars in London.<sup>13</sup> Similar machines, such as a steam engine developed by the French brothers P rier, were erected in France at the same time. However, as Otto Mayr remarks in his book *The Origins of Feedback Control*, the P rier scheme was ultimately unsuccessful, simply because of 'its poorer dynamic properties.'<sup>14</sup>

<sup>13</sup> Dickinson, Henry Winram. 1963. *A short history of the steam engine*. London: Cass. p 83.

<sup>14</sup> The P rier machine used a float valve for self-regulation where the Boulton & Watt engine used the famous 'governor.' See Mayr 1970, 117.

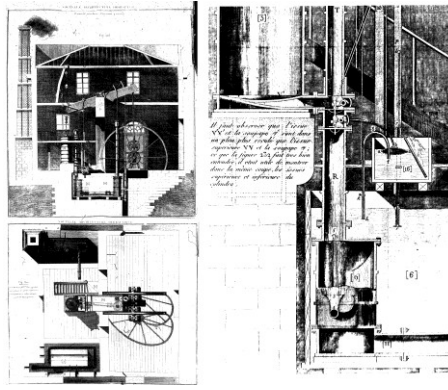


fig 1.06 Pèrier steam engine with float valve. 1790. Steam engine of the French brothers Pèrier as in Riche de Prony. 1790. *Nouvelle architecture hydraulique, contenant l'art d'élever l'eau au moyen de différentes machines, etc.* Engine parts and building elements are integrated with one another.<sup>15</sup>

## The mechanisation of architectural thinking

If mechanical structures constituted substantial parts of architecture, then the question arises of whether mechanics were integrated into architectural design thinking. The question could be re-formulated by asking, which conditions were present historically to enable mechanisation to take a central role in architectural thinking? Tzonis and Lefaivre point out in their essay 'The machines in architectural thinking' (1985) that '[t]he machine seems to have been one of the objects most narrowly associated with the fortunes of architecture.<sup>16</sup> They argue that before the machine could be assimilated by building technology [or vice versa] it had to be introduced into the thinking of the architect.

<sup>15</sup> Riche de Prony, Gaspard Clair François Marie. 1790. *Nouvelle architecture hydraulique, contenant l'art d'élever l'eau au moyen de différentes machines, etc.* Paris: Firmin Didot. p 259; Mayr 1970, 116.

<sup>16</sup> Tzonis and Lefaivre 1985, 16.

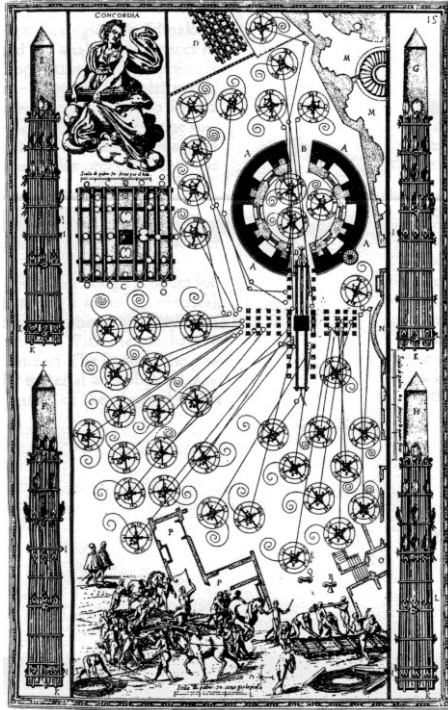


fig 1.07 Domenico Fontana (1543-1607). *Drawing of the erection of the Vatican obelisk*. 1590. Plan for raising the Vatican obelisk. The winches are shown by the circles, from which the ropes are connected to the scaffold tower. The scene is watched over by Concordia, the Roman goddess for agreement, understanding and harmony.<sup>17</sup>

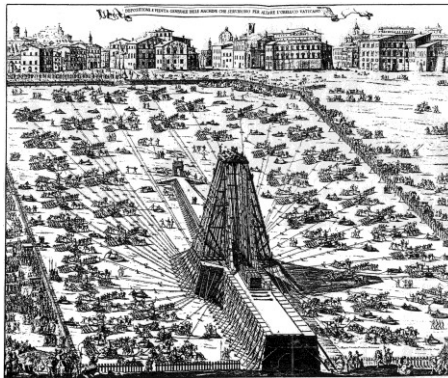


fig 1.08 Carlo Fontana (1634-1714). *Drawing of the erection of the Vatican obelisk*. 1694. The Vatican obelisk being set up in the Piazza of St. Peter in Rome, Templum Vaticanum. The obelisk is raised by a tackle suspended from the top of Fontana's scaffold tower, 48 winches are in position and the ropes are taut.

Tzonis and Lefaivre's hypothesis is that architects' interest in the machine metaphor was the expression of an increasing presence of analytical thinking in scientific-technological discourse, which was eventually reflected in the practices of building design. They argue

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<sup>17</sup> Tzonis 1985, 19.

that around the end of the seventeenth century mechanisation became the main driver of empirical verification and analytical backing of architectural thinking.<sup>18</sup> Siegfried Giedion agrees in *Mechanization takes Command* (1948) and locates the roots of modernity's machine enthusiasm in this period.<sup>19</sup>

As Tzonis and Lefaivre explain in an earlier article the machine metaphor has been established in architectural discourse as part of an incongruous debate between utilitarian and artistic positions.<sup>20</sup> Design has taken two irreconcilable directions: '*design developed as a science*, where emphasis is placed on the minimization of cost in the production or use of the design object, and *design developed as an art*, where the focus is on the maximization of pleasure derived from the design object.'<sup>21</sup> The Royal Academy of Architecture (established in Paris by Jean-Baptiste Colbert in 1671), was a manifestation of the utilitarian approach which, in opposing archaic principles ruled by divine law, sought to establish modern sets of norms 'warranted by the need to maximize utility and minimize cost.'<sup>22</sup> As is always the case, such intense searches for a new beginning engender intellectual rivalry. In this case, the emphasis of the scientific approach was opposed by the École des Beaux-Arts, founded shortly after the French Revolution. This school treated architecture not as a rational discipline but as art, characterized by a carefully developed sense of spatial order, human experience and personal identity. Architecture's ambivalent affinity with the practices of science and art inevitably found its expression in the formulation of architecture as an ideal container for human activities.

### *Buildings are utilitarian instruments for control*

On the one hand architects developed design methodologies, which 'after a systematic collection of empirical [evidence] (sic) and a long series of experiments, succeeded in

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<sup>18</sup> See by same authors, '1650-1800: Les systèmes conceptuels de l'architecture' (Cambridge, Mass., 1975) and Tzonis, Freeman, Berwick, 'Discourse Analysis and the Logic of Design' (Cambridge, Mass., 1978). Both papers have been published in *Conceptual systems in design: Two papers*, *Harvard Graduate School of Design Publication Series in Architecture*, no. 7817.

<sup>19</sup> Giedion 1948, 7.

<sup>20</sup> Tzonis and Lefaivre 1975, 4-7.

<sup>21</sup> Tzonis and Lefaivre 1975, 6.

<sup>22</sup> Tzonis and Lefaivre 1975, 4.

establishing a causal relationship between causal means and desired utilitarian effects.<sup>23</sup> This period was the peak of the mechanistic paradigm with Sir Isaac Newton formulating his *Philosophiæ Naturalis Principia Mathematica* (1687).<sup>24</sup> At the same time, as architecture's engagement with the ideas and innovation of the emerging Industrial Age grew, architecture was celebrated as machine for the control of human beings. In particular, it was the fascination with the control of the human body as it moves, rests, breathes, etc., that gradually began to inform the design of buildings. Indeed, as the machine became the eponym for efficiency and rationalisation the first buildings conceived as machines were compared to large instruments. 'This comparison was made by scientists rather than architects themselves.'<sup>25</sup> 'A hospital room is truly a machine for treating patients' writes French scientist Jean-Baptiste Le Roy in 1787, reflecting the general approach of the times.<sup>26</sup>

Written in the same year, English philosopher and social theorist Jeremy Bentham's notorious proposal for a building-control-machine, the *Panopticon* (1791), can be considered as one of the most radical expression of this development.<sup>27</sup> The Panopticon is nothing more than '*a simple idea in Architecture!*'<sup>28</sup> Bentham enthused in the preface to his book. In the Panopticon, Bentham placed 'his hopes for the solution of all socioeconomic problems and reforms in an architecture that was not capable yet of being conceived by architects.'<sup>29</sup>

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<sup>23</sup> See Tzonis and Lefaivre 1975, 6. For a detailed discussion see Tzonis and Lefaivre 2004, 25.

<sup>24</sup> Luis Fernández-Galiano argues that though the mechanistic paradigm had its roots in the works of Descartes and Bacon, its most representative figure doubtlessly is Sir Isaac Newton. On the other hand, Fernández-Galiano draws attention to the work of Pierre-Simon, marquis de Laplace, whose *Treatise of Celestial Mechanics* is the most thorough and eloquent expression of a mechanical conception of the world (2000, 35).

<sup>25</sup> Tzonis and Lefaivre observe the curious occurrence that the instrument-architecture comparison was mentioned in studies carried out by medical doctors, mathematicians and physicists attached to the French Academy of Science, and not in the Académie d'Architecture by architects. See Tzonis and Lefaivre 2004, 25.

<sup>26</sup> See 'Précis for a Work on Hospitals' written as a report to the Académie Royale des Sciences (written 1777, published 1787), partially re-printed in Tzonis and Lefaivre, 2004, 411-414.

<sup>27</sup> For original text see Bentham 1791. For an edited and introduced version see Bozovic 1995. Bentham has not written a book per se. The Panopticon writings actually consist of a series of letters written from Russia in 1787 'to a friend in England' (1995, 1).

<sup>28</sup> Bentham 1791, 31 [italics and punctuation in original].

<sup>29</sup> Tzonis and Lefaivre 2004, 25.



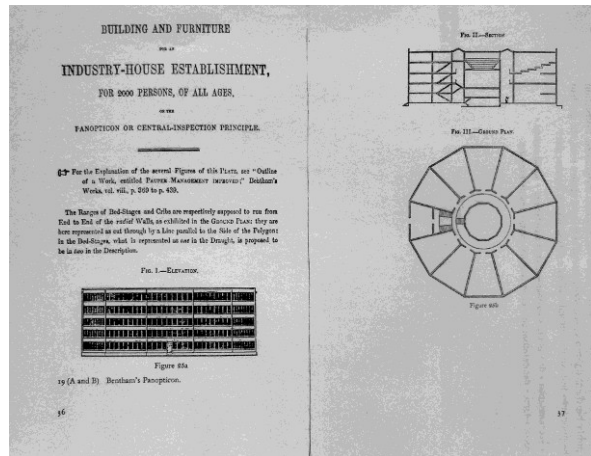


fig 1.09 Jeremy Bentham. *Panopticon, or the Inspection-House*. 1787.

The design allows an observer to observe all inmates of the Panopticon without them being able to tell whether they are being watched or not. The terms ‘pan’ and ‘opticon’ form the neologism describing that all (pan) can be observed (opticon). The ‘inspector’s house’ is located at the centre and the inmates are located around the perimeter.

Bentham’s prison gained its iconic status through the work of French philosopher Michel Foucault. In his seminal book *Discipline and punish: the birth of the prison* (1975) Foucault installs the architectural figure of the Panopticon as a disciplinary mechanism of power.<sup>30</sup> Utilitarian ideals such as Bentham’s disciplinary approach laid the foundation for the modern movement, infusing the practice of design with the paradigms of rationalisation and control. Manuel De Landa describes the Panopticon as a ‘surveillance diagram.’ “The name of this architectural machine reveals the strategy behind it: to make optics (the surveying eye, the watching gaze) ubiquitous and pervasive through the use of technology.”<sup>31</sup>

### *Buildings are artistic devices for corporeal excitement*

On the other hand a more artistic approach considered ‘the building as a container of human bodies and the human body itself as a machine reacting to external forces.’<sup>32</sup> This approach, conveyed by the École des Beaux-Arts, installed architecture as an object that causes sensations. Buildings were conceived artistically as devices for enlightenment,

<sup>30</sup> See Foucault 1995 [1975], chapter 3, Panopticism, p. 195 ff. It was Foucault’s famed *Surveiller et punir: Naissance de la prison* that brought the Panopticon to the attention of the wider public in 1975.

<sup>31</sup> De Landa 1991, 203.

<sup>32</sup> Tzonis and Lefaivre 1975, 6.

delight and enjoyment. In contrast to the methodical designer-engineer, artist-architects such as Étienne-Louis Boullée<sup>33</sup> could not empirically support their theories on the effects of form on the human perception.<sup>34</sup> As Tzonis and Lefaivre point out, these architectural visions remained limited to general intention, particularly in the case of Boullée, whose designs remained unbuilt but became powerful emblems of visionary architecture.<sup>35</sup>

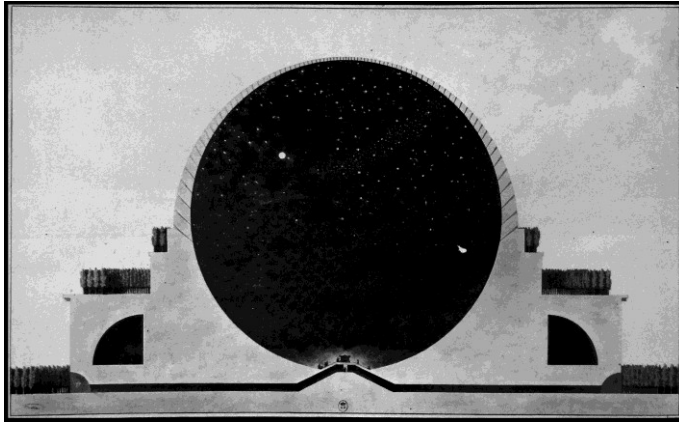


fig 1.10 Étienne-Louis Boullée. *Cénotaphe à Newton*. 1784.

The project is represented by a series of large tinted drawings showing the cenotaph in plan and section. The perfection of the spherical form represents a world complete in itself, integrated and full of repose (Boullée in Rosenau 1953, 5). There are two sections, one representing day while the other represents night. Day is achieved by interior effects of sunlight unobtainable in Boullée's lifetime. Night is achieved by slits in the dome, allowing light rays to penetrate (ibid., 19).

According to Tzonis and Lefaivre the architectural thinking of architects like Boullée installed architecture as a mechanism that is seen to 'affect the body-psyche complex by

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<sup>33</sup> Other influential figures were the French architect and theoretician Nicolas Le Camus de Mézières (1721–1789) and French architect Claude-Nicolas Ledoux (1736–1806).

<sup>34</sup> In the introduction to his book *Architecture, Essai sur l'Art* Boullée distances his definition of architecture from Vitruvius' 'art of building' and argues that what constitutes architecture is the process of its creation, as architecture is a product of the mind. Consequently, Boullée defines architecture as the *art of designing* with building only considered an auxiliary art, which, he proposes, could be called the scientific side of architecture. See English translation of text in Rosenau 1976, 83 ff. Boullée's book advocates an emotive architecture illustrating his work from 1778 to 1788, which mostly comprised designs for public buildings. The book was only published in 1953; see editorial notes and original French text in Rosenau 1953.

<sup>35</sup> Tzonis and Lefaivre 1975, 6. Boullée wanted to become a painter initially but was induced by his father, who held a position as an architect in the Bâtiment du Roi, to follow the same profession. The sole and notable survivor of Boullée's built work is the Hôtel Alexandre, rue de la Ville l'Évêque (built 1763-66) in Paris. Boullée ideas and teaching had major influence on the development of architecture.

causing it to have sensation.<sup>36</sup> Tzonis and Lefaivre further explain that architecture is seen as composition artificially assembled to cause effects in man: ‘according to the machine framework, shapes, shadows, and tones are like vectors entering into a system, generating in the body-psyche complex reactions either of pleasure or of pain.’<sup>37</sup> The conception of architecture as machine influencing the body-psyche complex gave it the power to cater for enlightenment and delight of human beings inhabiting such architecture. Design developed as art, as practices at the École des Beaux-Arts helped formulate a better understanding of the joyful and artistic reciprocities between buildings and machines. In this ethos architectural thinking has been less constrained by an obsessive search for an idealised functionality, and furthermore buildings could be conceived as mechanisms designed to cause sensations. Luis Fernández-Galiano notes by reference to both Bentham’s Panopticon and Boullée’s Cenotaph for Newton that these two projects were spatial manifestations of the material and cultural universe of Newton and the Enlightenment, and as such they were ‘notorious precedents of the physical and conceptual works in which modern architecture emerged.’<sup>38</sup>

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<sup>36</sup> Tzonis and Lefaivre 1975, 6.

<sup>37</sup> Tzonis and Lefaivre 1975, 6.

<sup>38</sup> Fernández-Galiano 2000, 39.

## s2 | Architectural design embraces the machine

Construction of movement – László Moholy-Nagy and the first architectural machines –  
Event machine – Technomorph machine-architecture

In modernity, a general machine-age enthusiasm strived for aesthetic expression and a new logic of production. By borrowing principles of method, standardisation and scientific management from engineering and industry, architecture sought to re-imagine its unique position in society as art and as an important economic activity.<sup>39</sup> Prophets of the productive and rationalistic meanings of technologization such as Le Corbusier projected their enthusiasm for industrial mass-production and standardization onto architecture.<sup>40</sup> Le Corbusier's much quoted rubric 'a house is a machine for living in.'<sup>41</sup> epitomized an attitude through which architecture was affirmed as an 'environment of the machine aesthetic.'<sup>42</sup> The machine embodied the functionalist dream of architectural space as something that could be managed and optimised in cooperation with machines.<sup>43</sup> But the mechanical machine metaphor has not only severed the ties between human labour and the object (which has subsequently become a product), but it has also exposed space as something manageable under the auspices of machinic function, control, efficiency and optimisation.

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<sup>39</sup> Guillén 2006.

<sup>40</sup> Le Corbusier read Frederick W. Taylor's books [The Principles of Scientific Management, 1911] while fighting in the trenches of the World War I (Guillen 2006, 64).

<sup>41</sup> Le Corbusier 1946 [1923], 100. Original French: 'Une maison est une machine à habiter.'

<sup>42</sup> As Banham points out, the phenomena, that designers and architects are trying to 'fix the correct new style of the Machine age' was quite literally exemplified by Le Corbusier's sweet spot for ocean liners, aeroplanes and automobiles. See Banham [1969] 1984, 122.

<sup>43</sup> The impact of machines on the design of the architectural environment has found its historical documentation in works such as Siegfried Giedion's *Mechanization takes Command: A contribution to anonymous history* (1948), a work standing with its eponymous title for the mechanical extension of architecture.

## Construction of movement

Art movements such as Futurism reinforced the position of the machine as modernity's symbol for progress, through its fascination with speed, technology, youth and violence.<sup>44</sup> As a progression of Futurism, and similarly fascinated with the machine, the Soviet Union's distinctive contribution to architectural modernism was Constructivism, applying scientific principles and technology to art and design.<sup>45</sup> In his 1924 manifesto-like treatise *Stil' I Epokha (Style and Epoch)* Moisei Ginzburg called for a fusion of engineering and architecture based on the machine as principle formula for a new socio-technical reality.<sup>46</sup> Another perspective was offered by the architect Iakov Chernikhov, possibly the most successful designer of industrial buildings of his age.<sup>47</sup> Chernikhov expressed his belief in the machine as metaphor and the method for design in architecture: '[t]he mechanization of movement and building in life is peculiar to our time, the intense development of industrial production and of technology in general have radically changed our way of life and generated new needs, new habits, and new tastes.'<sup>48</sup> In his book *The Construction of Architectural and Machine Forms* (1931) Chernikov advocated the machine as model for architectural composition,<sup>49</sup> while at the same admitting that buildings were static and their potential for real, kinetic movement was stopped in time.<sup>50</sup> Chernikov remained an outsider to the Moscow scene – more influenced by the rigorous formal abstractionism of Suprematist thinking than by the calculated, technological fetishism of Ginzburg.<sup>51</sup> Where Chernikov stopped short of designing true 'machine architecture' on the building scale, the crème-de-la-crème of the Russian avant-garde, including Melnikov, Lissitzky and Tatlin, amongst others, had grand plans for kinetic architectures.

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<sup>44</sup> Futurism most influential was the Italian writer Filippo Tommaso Marinetti, who launched the movement in his 'Futurist Manifesto,' which he published for the first time on 5 February 1909 in *La gazzetta dell'Emilia* (Marinetti 2006). But it was the publication of his *Le Figaro* manifesto in Russia, which created a buzz among an entire generation of artist (Salter 2010, 11).

<sup>45</sup> Bowlt 1988, 204-61 and Lodder 1983, 90-94.

<sup>46</sup> Ginzburg 1983.

<sup>47</sup> Guillén 2006, 77.

<sup>48</sup> Quoted in Bowlt 1988, 259-60.

<sup>49</sup> Cooke 1989.

<sup>50</sup> Cooke 1995, 113.

<sup>51</sup> Salter 2010, 363; note 11.

### *Vladimir Tatlin's Tower*

The boldest scheme was Vladimir Tatlin's *Monument to the Third International* (1919). Tatlin's colossal proposal for a 400 meter high, ziggurat-like structure was envisioned as a towering symbol of modern architecture's assimilation of technology.<sup>52</sup> Tatlin imagined the monument to be 'built on the basis of entirely new architectural principles,' and to be the place of 'most intense movement.'<sup>53</sup>



fig 1.11 Vladimir Tatlin. Drawing of the *Monument to the Third International*. circa 1920.

Tatlin's tower achieved its only material manifestation in a 6 metre tall model that was exhibited in the Academy of Arts in Petrograd in 1920. Often hindered by their vastness – Tatlin's tower allegedly would have used up all of Russia's available steel – Constructivist proposals, however, instilled in architecture a desire for liberation from inertness and sitedness.

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<sup>52</sup> Zhadova 1988.

<sup>53</sup> Zhadova 1984, 5; Lodder 1983, 56.

### *Frederick Kiesler's Endless Stage*

In a more manageable format the utopia of transformation was realized by visionary designer and architect Frederick Kiesler in his stage designs.<sup>54</sup> Following his initiation as stage designer in 1923 in Berlin when – without prior experience in stage design – the thirty-three year old created an unusual electro-optical-mechanical scenography for Karel Čapek's dystopian science-fiction robot drama *R.U.R. (Rossum's Universal Robots)*<sup>55</sup>, Kiesler's *Raumbühne* (literally 'space stage') was realised in prototype form at the International Exhibition of New Theatre Techniques in Vienna in 1924. Unlike Kiesler's earlier unbuilt designs, such as the *Railway-Theatre*, where the audience circulates the stage in spiral motions,<sup>56</sup> the *Raumbühne* structure was constructed as an open tower in the centre of the Vienna Konzerthaus as multistorey set of platforms joined together by a spiral formed ramp.<sup>57</sup> Kiesler's extraordinary formulation of machine-scenic construction originally included the use of an elevator at the centre of the structure, but this was not realised.<sup>58</sup>

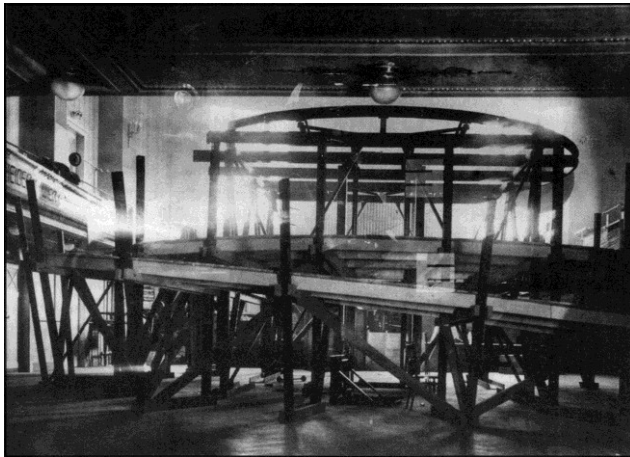


fig 1.12 Frederick Kiesler. General view of the *Raumbühne* (space stage). 1924.

Barbara Lesák compares Kiesler's *Raumbühne* design with Tatlin's tower, stating that both are using 'the inherent symbolic content of the spiral.'

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<sup>54</sup> Lesák 1988.

<sup>55</sup> Lesák 1988, 70. The premiere performance, staged at the Theater am Kurfürstendamm, was announced as 'utopian collective-drama.'

<sup>56</sup> See Lesák 1988, 52.

<sup>57</sup> Lesák 1988, 43.

<sup>58</sup> Lesák 1988, 43.

As artistic director of the exhibition, Kiesler brought together some of the most radical mechanized European theatrical experiments of the day, from Russian Constructivist designs of Popova and Lissitzky to Schwitters's *Merzbühne* and abstract mechanical designs by Oskar Schlemmer and László Moholy-Nagy.<sup>59</sup>

### László Moholy-Nagy and the first architectural machines

The progressive technologisation of the stage has also occupied the Hungarian artist, theoretician and educator László Moholy-Nagy. He developed the theatre-utopia *Entwurf für eine kinetische konstruktion, system, bau mit bewegungsbahnen für spiel und beförderung* [commonly translated as 'Design for a kinetic construction'] in 1922.<sup>60</sup>

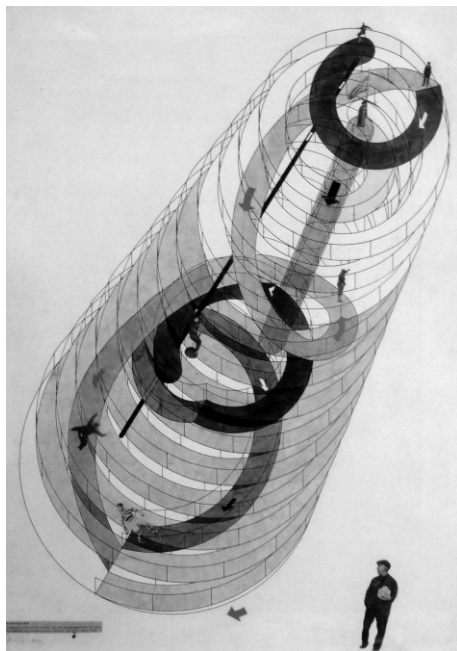


fig 1.13 László Moholy-Nagy. *Kinetisch-Konstruktives system. Bau mit Bewegungsbahnen für Spiel und Beförderung*. [Kinetic-constructive system. Building with movement rails for play and transportation]1922.

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<sup>59</sup> Lesák 1988, 100+102.

<sup>60</sup> Similar to Kiesler, Moholy-Nagy would only work in stage context for a short time. His design for the 1928 production of Jacques Offenbach's *Tales of Hoffmann* at the Staatsoper Berlin and the scenography for Erwin Piscator's *Der Kaufmann von Berlin* employed careful illuminations of translucent surfaces in the former as well as all kinds of mechanical paraphernalia, like treadmills, elevators and moving ramps in the latter, causing the critic Bernhard Diebold to state: 'What an apparatus!' See Willet, John. 1978. *The Theatre of Erwin Piscator: Half a Century of Political Theatre*. London: Eyre Methuen. p 100. In terms of scale, these stage designs can be seen as the most 'architectural' manifestation of Moholy-Nagy theatrical ideas.



Based on his educational experience and lectures at the Bauhaus between 1923 and 1928 Moholy-Nagy set out his visions in his major book *Von Material zu Architektur* (1928), later published in English as *The New Vision* (1930). The publications functioned as an encyclopaedia of Moholy-Nagy's fascination with technologically augmented forms of expression and aesthetic impulses provided by the mechanized world. As artist and media theorist Chris Salter observes, the book culminated 'in the exploration of space as a dynamic material through built (i.e. architectural) form.'<sup>61</sup> Illustrated by images from his own as well as his students' work Moholy-Nagy's concept of *Raumgestaltung* (or *spatial design*) is articulated as an application of new materials and techniques for experimentation with kinetic structures.

In his educational approach, Moholy-Nagy encouraged the design and construction of mechanical contraptions for the extension of bodily experiences. The broader curriculum of his *Vorkurs* [The Preliminary (Foundation) Course] was designed to foster 'spontaneity and inventiveness' and give the student a 'universal outlook' through experimentation with tools, machines and different kinds of material in order to provide 'the most direct experience of the organic connections of handicraft and art.'<sup>62</sup> Taught at both the Bauhaus in Dessau as well as the New Bauhaus in Chicago, the student was not asked to 'deliver premature *practical* results.'<sup>63</sup> Instead, embedded in the broader spectrum of biological and physical studies including modelling, drawings, photography and literature, device-making should furnish future architects with 'sensory training,' 'experience with materials' and 'tactile exercises.'<sup>64</sup>

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<sup>61</sup> Salter 2010, 38.

<sup>62</sup> Moholy-Nagy 1947, 21.

<sup>63</sup> Moholy-Nagy 1947, 21 [italics in original].

<sup>64</sup> Moholy-Nagy 1947, 23+25.

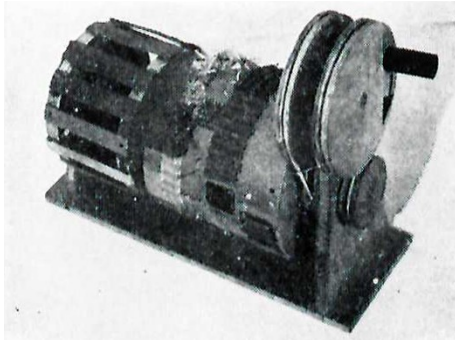


fig 1.14 Rudolf Marwith. *Revolving tactile drum with contrasting tactile values*. Bauhaus, 1928.

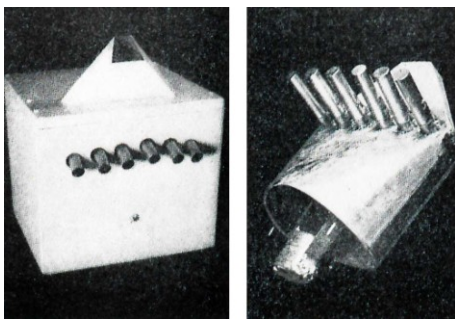


fig 1.15 Charles Niedringhaus. *Smell-o-Meter*, for mixing six different odours. New Bauhaus. 1938.

### *The first architectural machine of the modern age*

Although the continuum of architecture's conjunction with machines has many beginnings, the use of purpose built devices and machines as experimental medium in architectural education by Moholy-Nagy seems to mark a particular moment in time where the exploration of machines held promises for the advancement of architectural design. Referring to the developmental stages of sculpture, 'from mass to lightening of weight, from static treatment to movement,'<sup>65</sup> Moholy-Nagy positions the kinetic sculpture as the most advanced stage, noting that 'the material is employed as a vehicle of motion' adding to 'the three dimensions of volume, a fourth – movement – (in other words, time is added)'.<sup>66</sup> Moholy-Nagy contextualises his own fascination with time-based

<sup>65</sup> Moholy-Nagy 1947, 43.

<sup>66</sup> Moholy-Nagy 1947, 47.

media in the history of kinetic sculpture, referring to Futurist fascination with dynamism and Russian Constructivist refusal of static in favour of kinetic rhythms.<sup>67</sup>

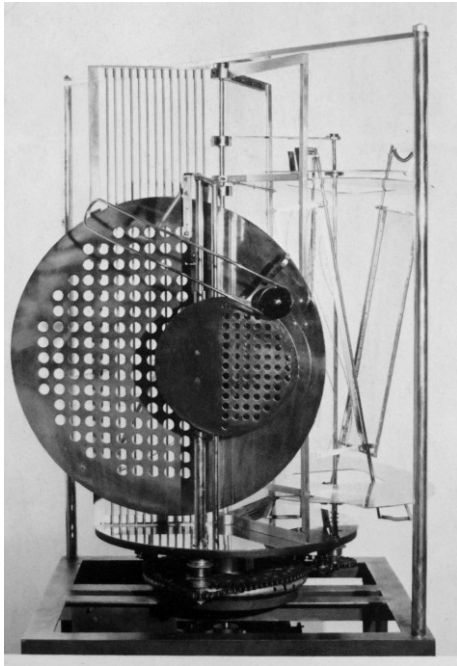


fig 1.16 László Moholy-Nagy. *Light-Space-Modulator*. 1922-1930.

‘This moving sculpture had 140 light bulbs connected with a drum contact. This was arranged so that within a two-minute turning period, various coloured and colourless spotlights were switched on, creating a light display on the inside walls of a cube.’

Moholy-Nagy’s position becomes clearest when, in a statement in his short 1922 manifesto ‘The dynamic-constructive system of forces’, he acknowledges the potential of device-making for spatial design: ‘The first projects looking toward the dynamic-constructive system of forces can be only experimental demonstration devices for testing the relations between man and material, power and space.’<sup>68</sup>

Two years after leaving the Bauhaus Moholy-Nagy completed the *Light-Space-Modulator* (1922-1930) which sums up his experiments there.<sup>69</sup> Considered to be one of Moholy-Nagy’s most original creations, and given its mechanical complexity, the sculpture is

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<sup>67</sup> Moholy-Nagy 1947, 49.

<sup>68</sup> Quote from manifesto ‘The dynamic-constructive system of forces’ originally published in collaboration with Alfred Kemeny, in *Sturm* no. 12/ 1922, Berlin, quoted in Moholy-Nagy 1947, 49 and in Passuth 1985. Part II, p. 290.

<sup>69</sup> See Passuth 1985, Part I, 53.

considered to be ‘a pioneering exploration of light and motion machines, and as such it set a precedent for many subsequent mechanized sculptures.’<sup>70</sup>

Existing in two forms simultaneously, as a metal-glass kinetic structure and its projected image, the piece reveals its meaning when structure, light and motion come together. Art historian Krisztina Passuth explains that with the *Light-Space-Modulator* Moholy-Nagy created a new genre: the *beautiful machine*.<sup>71</sup> Its appearance has nothing to do either with ‘the Dadaist’s anthropomorphic-ironic pseudo-mechanisms or with the laconic brutality and humour of the ready-mades, i.e. with any of those tendencies which deliberately set mechanism against the ideal of beauty.’<sup>72</sup> As a machine the *Light-Space-Modulator* did not only embody the potential of machines to be imbued objects with qualities beyond their mechanical nature.<sup>73</sup> It also infused the praxis of architectural design with the possibility to enquire time-based, ephemeral and sensual issues of human experience of space.

## Event machine

Visions of performative buildings and living cityscapes resurfaced when in the 1960s designers and collectives tried to address architecture’s ‘failure to respond to rapidly changing political-social-cultural-technological fault lines.’<sup>74</sup> Seeking to reinvent architecture in an age influenced by televisual media, advertising, space exploration, submarines, social upheaval and expansion of the mind by psychedelia, the London based collective Archigram was launched with the first issue of their eponymous publication in 1961. Formed by Peter Cook, Ron Herron, Mike Webb, Warren Chalk, David Greene and Dennis Crompton the group channelled its collective output into publications as exhibitions such as the 1963 *Living Cities* exhibition at the Institute of Contemporary Art (ICA), London. The typical Archigram project ‘provides a new agenda where nomadism is

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<sup>70</sup> The *Light-Space-Modulator* was built by Moholy-Nagy himself with the aid of Otto Ball, as skilled mechanic, and Istvan Sebok, a young architect working in Gropius Berlin office and the theatre department of AEG. See Schobek 1993, 25.

<sup>71</sup> See Passuth 1985, Part I, 54 [italics in original].

<sup>72</sup> See Passuth 1985, Part I, 55.

<sup>73</sup> As Daniel L. Schodek points out in his great book *Structure in Sculpture*, the *Light-Space-Modulator* was a fragile structure and as such prone to failure. It had to be amended in order to improve its structural integrity. This is a process all too common with mechanised kinetic sculptures. See Schodek 1993, 25-26.



Archigram members Dennis Crompton, Mike Webb and David Greene had a particular enthusiasm for gadgets, technologies and machines, which inspired their projects with the design of space modules, landing pods and submarines. David Greene's drawings for *Living-pod* (1965) suggest a technologized version of Kiesler's *Endless House* [c4. s2 Architectures of partial bodies]. Architecturally, the *Living Pod* is a response to events and personal needs that are not translated into 'formal limitations' anymore but are symbolized by a 'mechanized liberation.'<sup>78</sup> Based on the paradigms of the trailer home, prefabricated housing and the 'possibility of increased personal mobility' the *Living Pod* 'is an appliance for carrying with you' in a city that is a 'machine for plugging into.'<sup>79</sup> Greene states in reference to Banham, that '[i]t is likely that under the impact of the second machine age the need for a house (in the form of a permanent container) as part of man's psychological make-up will disappear.'<sup>80</sup>

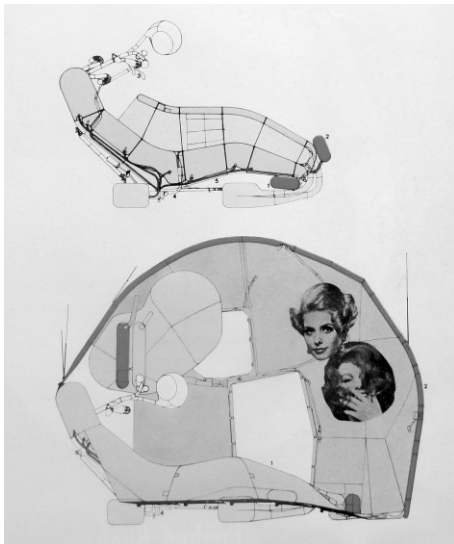


fig 1.19 Mike Webb. *The Cushicle*. 1966.

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<sup>78</sup> Cook 1999, 50.

<sup>79</sup> Greene 1966, 570.

<sup>80</sup> Greene 1966, 570.

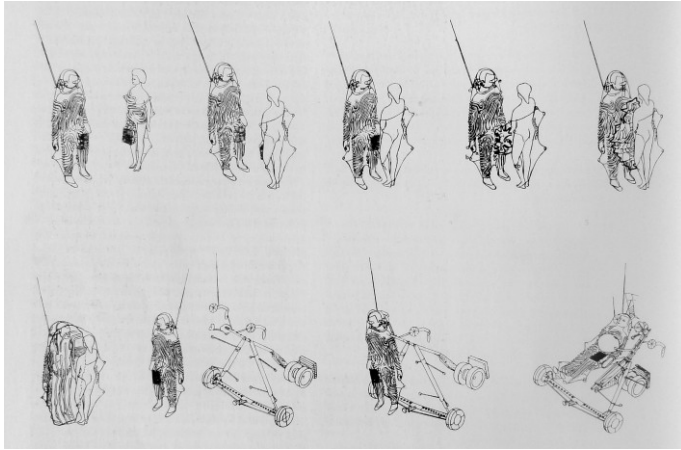


fig 1.20 Mike Webb. *Suitaloon*. 1968.

As a follow-up project the *Suitaloon* is taking inspiration from the space suit as minimal house. The project contemplates the idea of ‘plugging into’ other suits.

In his appraisal of the *Living Pod* Greene contends that the capsule is still a ‘house’ pointing towards more impermanent and mobile designs. ‘The outcome of rejecting permanence and security in a house brief and adding instead curiosity and search could result in a mobile world.’<sup>81</sup> Archigram member Mike Webb developed the group’s fascination with autonomous portable architectural devices forming part of ‘a more widespread urban system of personalized enclosures.’<sup>82</sup> In his project description Webb describes *The Cushicle* (1966) as ‘an invention that enables a man to carry a complete environment on his back. ... It is a complete nomadic unit.’<sup>83</sup> The structural part, called ‘armature,’ forms the chassis and support for appliances and other apparatuses. Another constituent element is the enclosure, which is essentially an inflated envelope. As a personalised enclosure *The Cushicle* is imagined to enable an urban explorer to have ‘a high standard of comfort with minimum effort.’<sup>84</sup>

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<sup>81</sup> Greene 1966, 570.

<sup>82</sup> Cook 1999, 64.

<sup>83</sup> Cook 1999, 64.

<sup>84</sup> Cook 1999, 64.

## Technomorph machine-architecture

Peter Pfau and Wes Jones of San Francisco architectural firm Holt Hinshaw Pfau Jones argue for an expressive architecture – not one directly representational, since technology is becoming increasingly abstract and invisible, but *an architecture that is an object of excess*.<sup>85</sup>

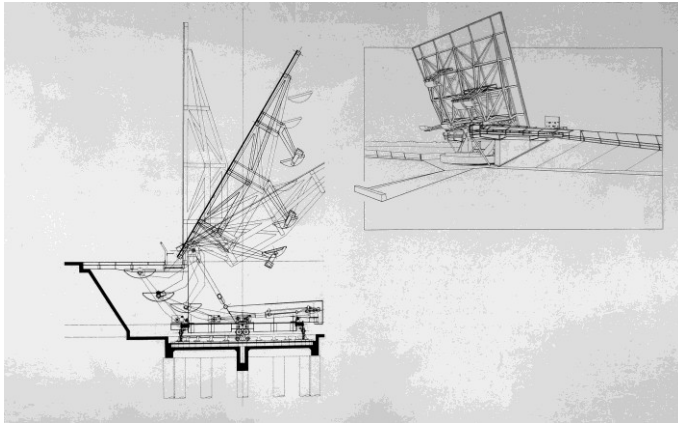


fig 1.21 Holt Hinshaw Pfau Jones. *Astronaut's Memorial*. 1988.

At the heart of this project lies the inversion of 'the architect's traditional subordination of technology to monument (Eiffel's structure for the statue of Liberty) in order to monumentalise technology itself.'<sup>86</sup>

Together with five other architects, Pfau and Jones exhibited their work at New York's P.S. 1 Museum in 1986 and the pamphlet *Building: Machines* (1987) was published shortly afterwards.<sup>87</sup> Also exhibiting at P.S. 1 was a young Neil M. Denari. He would become the most consistently radical exponent of a movement that would become known as 'machine-architecture'<sup>88</sup> or 'technomorph architecture.'<sup>89</sup> This movement was characterised by the incorporation of technical vocabulary in search of a new aesthetics, opposing the 'strangled architecture' of modern forms. Denari himself suggested that the proper understanding or reading of a mechanism 'is not in its form, but in its intention.'<sup>90</sup>

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<sup>85</sup> The fable is recounted in Betsky1990, 196 [italics in original]. The original text itself remained an unpublished manuscript.

<sup>86</sup> Hogben 1989, 45.

<sup>87</sup> McCarter 1987. Also see monographs Jones 1998 and Denari 1999.

<sup>88</sup> Cook and Llewellyn-Jones 1991, 156.

<sup>89</sup> Betsky 1990, 183.

<sup>90</sup> Denari in McCarter 1987, 20.



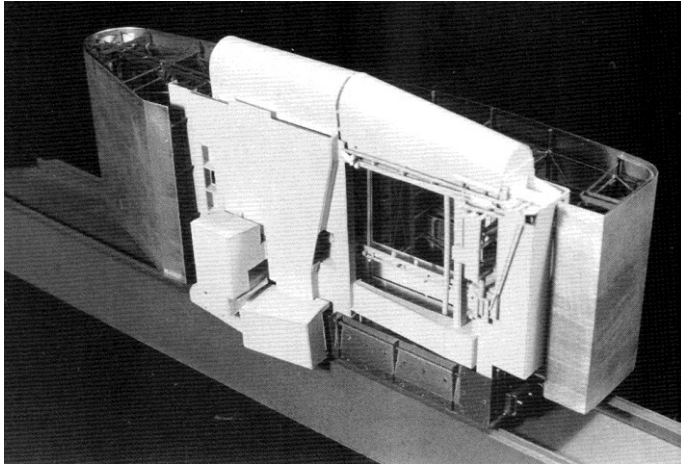


fig 1.22 Neil Denari. *Solar Clock*. 1987.

Clearly, the work of the ‘machine-architects’ is strongly influenced by its affinities to Russian constructivism. Being critically aware of these connections Kenneth Frampton suggested in his short essay in the *Building: Machines* pamphlet that ‘this work can be seen as a kind of “ruined” constructivism, a constructivism that has been reassembled out of the detritus of the modern world.’<sup>91</sup> In his critical assessment of Denari’s work Mark Dorrian conjured up a similar notion of assemblage. Like the ancient Greek slaying of the enemy warrior and the reconfiguration of the armour and remains into the trophy, Dorrian suggests, that ‘Denari’s building machine is slain and its fragments reconstituted into a haunted assemblage.’<sup>92</sup>

As with Russian constructivist and Futurist ideas, the obsessive assimilation of architectural corporeality with the machine had to be based on what constituted a machine in the first place. Like prosthetics – the dangerous supplements that first augment and then completely replace the anthropic body parts that wield them<sup>93</sup> – architectures born from corrupted machines are burdened by ambitions that once served other purposes. The campaign for transcending the monumental imperative of architecture by means of machines could not overcome the paradox imposed by industrialisation on architecture. The creation of the unique out of products of machines was overshadowed by the pre-configured formalism instilled in their architecture by assembling mass-produced components.

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<sup>91</sup> Frampton in McCarter 1987, 61.

<sup>92</sup> Dorrian 1994, 19.

<sup>93</sup> Bök 2002, 49.

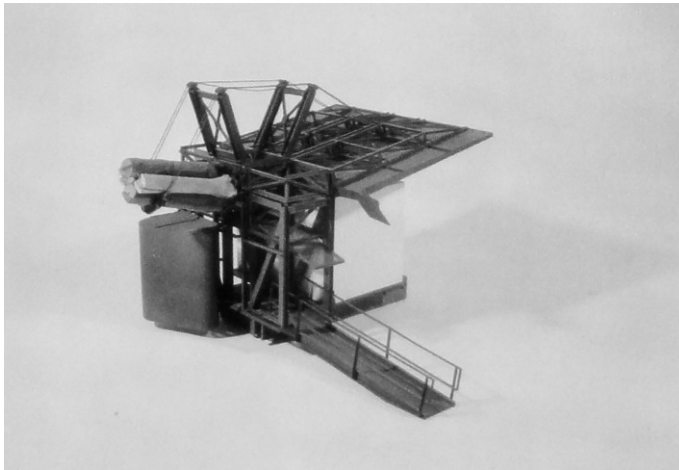


fig 1.23 Peter Pfau and Wes Jones. *Primitive Huts*, 1985.

‘The primitive hut should not be celebrated as a link to nature, but as step to man; as first building, not the last tree.’<sup>94</sup>

Kenneth Frampton critically maintained that the work of the ‘machine-architects’ implies the search for lost syntax as ‘neither modernism nor historicism is truly available today as a point of departure.’<sup>95</sup> With their *Primitive Hut* (1985) project Pfau and Jones posited an alternative to Marc-Antoine Laugier’s ‘empirically discovered’ origin of architecture in an attempt to resolve ‘architecture’s simultaneous existence as abstract institution and physical prescience.’<sup>96</sup> But the return of the repressed machine icon as ‘romantic ruin’ permeating and constituting the building inescapably removes it from the observer and installs the architecture as mythically distant object of contemplation.<sup>97</sup> Indeed, compared to Archigram’s joyful ‘situations’ and ‘the happening in the city,’ the ‘machine architecture’ drawings are evacuated of human presence in favour of their purist ‘machine aesthetics.’<sup>98</sup> Denari’s drawings are especially characterised by the presentation of the *machine* and its *manual*.<sup>99</sup> As the son of a helicopter engineer, and having worked at the graphics department of an aviation company,<sup>100</sup> Denari’s graphical work is an impeccable piece of

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<sup>94</sup> McCarter 1987, 43.

<sup>95</sup> Frampton in McCarter 1987, 61.

<sup>96</sup> Pfau and Jones in McCarter 1987, 43-47.

<sup>97</sup> Pfau and Jones in McCarter 1987, 43-47.

<sup>98</sup> Compare with Cook 1999, 16.

<sup>99</sup> Hogben 1989, 51.

<sup>100</sup> Cook and Llewellyn-Jones 1991, 156.

table-top engineering illustrated with keyed lists and tables of components as well as start-up, service and troubleshooting procedures.<sup>101</sup>

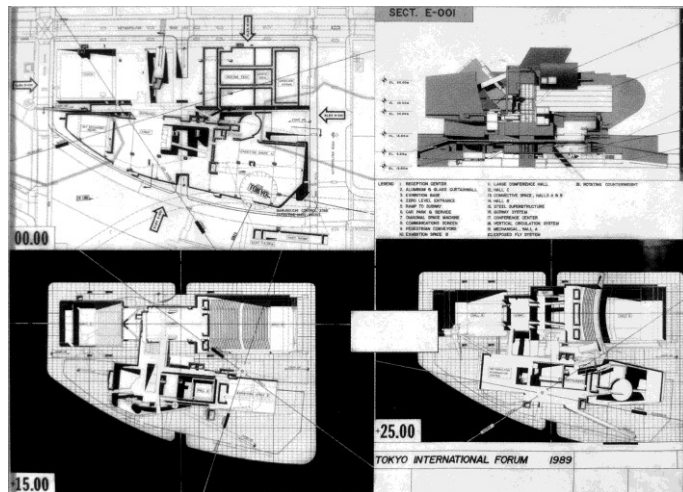


fig 1.24 Neil Denari. *Tokyo International Forum*. 1989.

Bryan Cantley continues the technomorph ‘machine-as-architecture’ typology. Both sited and site-less, Cantley’s projects suggest architectural prosthetics made from re-appropriated mass-products. An architectural ‘objet trouvé’ approach mixed up with graphical hieroglyphs creates a universe of machine-architectures where the mechanic function and semiotics are blurred.

<sup>101</sup> Hogben 1989, 51.

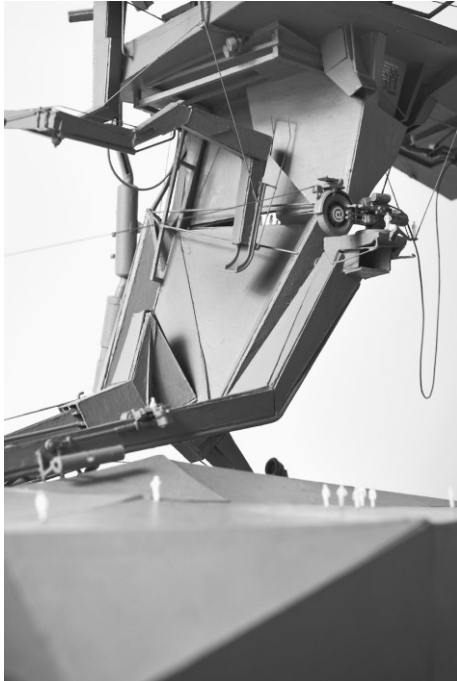


fig 1.25 Bryan Cantley. *MobileTech02*. 2011.

Yahohua Wang, a proponent of what could be labelled ‘digital technomorphism,’ has been thought by Wes Jones at Sci-Arc. Digital techniques and technomorphism inform one another. Wang’s projects typically deal with the reciprocal conditioning of bio-morph geometry and mechanical systems articulating a potential exit strategy for the ‘ruined’ or ‘object-trouv  ’ approach that overshadowed their purely technomorph predecessors.

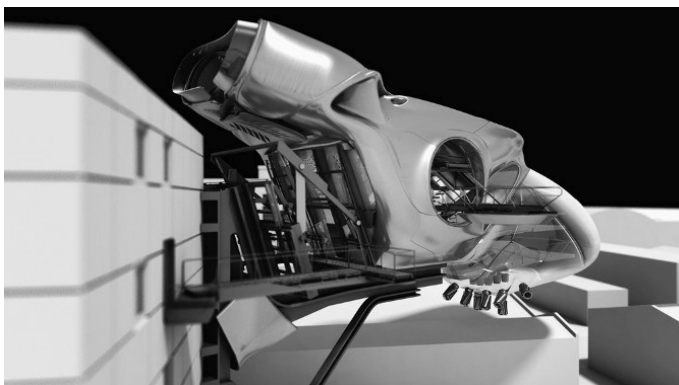


fig 1.26 Yaohua Wang. Exterior view of *Beijing House II*. 2011.

However, even though the external envelope suggests bio-inspired and bespoke design it is still tailored around an internal scaffold/ endoskeleton assembled from standardized construction products. Shedding the indoctrinations of industrial culture is an ambition

that underlies many contemporary approaches that seek a more co-constituting design approach on a system-level symbiosis, as can be observed in the work of Tom Wiscombe (composite structures)<sup>102</sup> or Marcos Cruz (corpology and embodied flesh).<sup>103</sup> In my own work this ambition has informed experimentation with soft machines where the frame-actuator/ skeleton-muscle duality is dissolved in favour of hybridised and co-constituting conceptions [c5. s3 Soft mechanical joints and actuators and c6], eventually leading to the articulation of the ‘embodied design’ strategy discussed in chapter 7.

Employing the machine as an appliance that executes and is created from industrial processes inevitably imports its mechanical heritage to architectural design – even more so when constraining the machine with stasis in models or drawings. The suggestion of dynamic mechanisms in non-dynamic media produces a gap between representation and purpose. Mark Dorrian contends that the mystifying, unfamiliar and indeterminate representation of Denari’s machine-architecture, its purposeful ‘dis-articulation ... between the building’s form and its operation,’ leaves the ‘relationship to what it houses uncertain.’<sup>104</sup> Lebbeus Woods, on the other hand, maintains that the potentiality of Denari’s designs lies precisely in the disjunction of design intention and program. Woods observes that ‘architecture-machines, intended for human inhabitation, that are inherently unpredictable, threaten the stability of conventions ... [they] impart a life of their own, independent of human will or control. Once designed and set into motion, it is impossible to say how they will perform.’<sup>105</sup> Inherent in Dorrian’s and Wood’s interpretations of technomorph machine architectures is the idea that their suggestive dynamism and movement reaches beyond their physical appearance and representation. The challenge of architecture’s stability through mechanics prompts not only the deconstruction and reassembly of its structures, but also reflections about the relationship between architecture and its imagination.

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<sup>102</sup> See discussion of Wiscombe’s ‘composite structures’ design approach by Sci-Arch teacher Ilaria Mazzoleni in Mazzoleni 2013, 22.

<sup>103</sup> Cruz 2014.

<sup>104</sup> Dorrian 1994, 19.

<sup>105</sup> Woods 1991, 43.

### s3 | Imaginary potential of architectural machines

A mythopoetic lesson in Architecture – Deconstruction and meaning of the machines –  
Thaumaturgic qualities of machines

The return to constructivism by the machine-architects in the 1980s coincided with the emergence of Deconstructivist Architecture. In the footsteps of Jacques Derrida's *Writing* (1967) architects such as Peter Eisenman claimed that 'architecture is a kind of writing.'<sup>106</sup> This time architects would endeavour to explain their work not from a structuralist point of view but through 'the metaphoric transfer and straightforward application of theory from outside to the practical domain of the architectural object.'<sup>107</sup> However, the fundamental difference between the perception of architecture and text lies in the synaesthetic construction of space by means of the built object in contrast to the ephemeral construction of meaning from written word. In a radical proposal *Three Lessons in Architecture* for the 1985 Venice Biennale Polish-born architect Daniel Libeskind<sup>108</sup> would attempt to bridge this difference and explore the relationship between architecture and language through the agency of machines. Libeskind's infamous exhibit converged the 'three moments of the machine' with 'the moment of reading,' 'the moment of remembering' and 'the moment of writing' architecture.<sup>109</sup>

Libeskind attempted to 'materialize philosopher Jacques Derrida's literary techniques within the process of construction.'<sup>110</sup> As student of Peter Eisenman and John Hejduk's at Cooper Union in the late 1960s and a postgraduate in the History and Theory of Architecture at Essex University under Joseph Rykwert, Libeskind could refer back to an educational pedigree that instilled his architectural contemplations with influences from

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<sup>106</sup> Robin Evans in a review of Eisenman's *Fin'd On T Hou S* exhibition at the Architectural Association in London. See Evans 1985, 68.

<sup>107</sup> Wigley 1990, 6.

<sup>108</sup> As a distinguished member of the Deconstructivist avant-garde, Libeskind developed his reputation through his early work, most notably the *Chamber Works* (1979) and *Micromegas* (1983) drawing series. His transition from architectural theorist and academic to practicing architect came with winning first prizes in international exhibitions, such as the Berlin 'City Edge' (1987) and the extension to the *Jewish Museum* (1989) which would eventually be built and form the basis of his international reputation.

<sup>109</sup> Libeskind 1991, 38.

<sup>110</sup> Salter 2010, 77.

the syntax of language and the imaginary and symbolical potential of machines. The equation could be formulated:

$$(\text{Hejduk machines} + \text{Eisenman Deconstructivism})^{\text{Rykwert historicism}} = \text{Libeskind's } \textit{Three Lessons in Architecture}$$

With these machines Libeskind acknowledged the integral role of machines for architecture. And by describing the machines as ‘Lessons’ Libeskind places the making of machines firmly into the curriculum of the architect.

... making machines, I discovered as I was doing this project, is an old task. Everybody needs machines. Vitruvius says that first of all an architect should make a machine – it is more important than making a city. Then he says you should make a theatre and other things. Alberti says this as well. When we read Vitruvius and Alberti and they say every good architect must first make a machine, to do architecture I must follow this tradition to its end.<sup>111</sup>

By purposefully not placing these machines in the contemporary technological tradition of the 1980s but giving them a dated sense of existence, using medieval technology and timber construction, Libeskind’s machines insist on a pre-industrial mechanical paradigm.<sup>112</sup> Through making machines Libeskind retrieves the intermingling experiences of handicraft and intellectual control and contrasts them with modern day modalities of industrial production. When architecture is more than just the practical art of building, can its beginning lie between the divine and the mythical, between mechanism and potential, between language and meaning?

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<sup>111</sup> Libeskind 1991, 39.

<sup>112</sup> The machines are ‘[e]xecuted in a “medieval” manner, with glueless joints and using no energy of contemporary kind’ See Libeskind et al. in Rossi 1985. vol. I. p. 164.

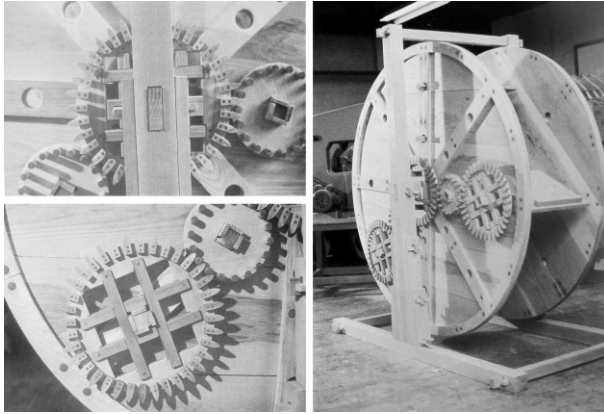


fig 1.27 Daniel Libeskind. Lesson A: Reading Architecture = Reading Machine. 1985.

'Executed in a "medieval manner, with glueless joints and using no enery of contemporary kind, this machine represents the triumph of spirit over matter; of candle light over darkness. It is made solely from wood, as are the books.'

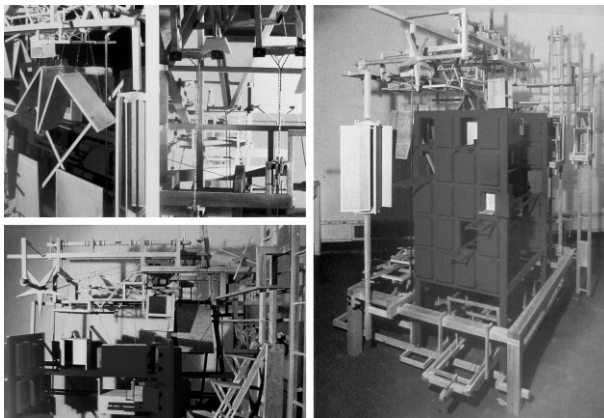


fig 1.28 Daniel Libeskind. Lesson B: Remembering Architecture = Memory Machine. 1985.

'It is executed in wood and retains in its structure the "hanging papers" seen by the King. This project represents the stage of Architecture's appearance and is a testament to its own manifestation.'



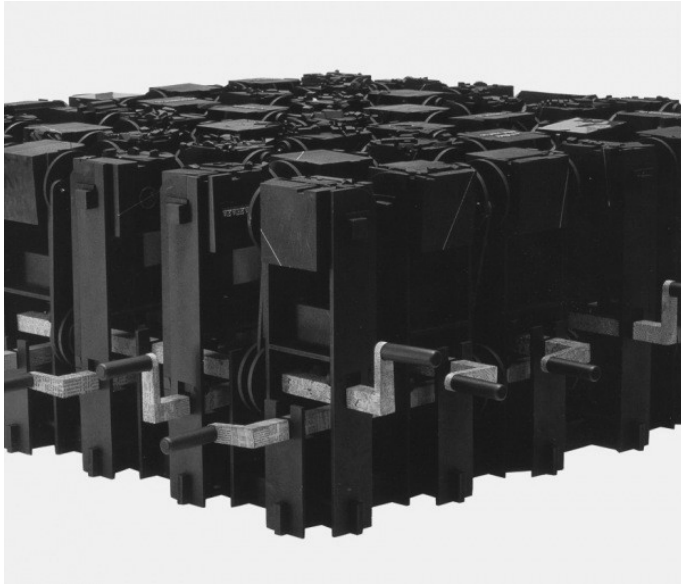


fig 1.29 Daniel Libeskind. Lesson C: Writing Architecture = Writing Machine. 1985.

'The machine is made of wood, graphite and metal and contains: 1. complex gear shaft driven systems which rotate, covered with multi-lingual papers; 2. 49 cubes which revolve at various speed ratios; 3. faces which show: a) Euro-African City; b) Saints who have emerged from the Biennale and who return to Roussel's Book of Saints; c) the empty Sky; d) divined graphic configurations based on horoscopes and omens.'

## A mythopoetic lesson in Architecture

Developed towards the end of his tenure as head of the architecture department at the Cranbrook University of Arts,<sup>113</sup> the *Three Lessons* were formulated as a response to one of Aldo Rossi's ten themes for the *Third International Exhibition of Architecture* at the Venice Biennale in 1985. Libeskind chose to address the urban problem of Palmanova (a medieval fortress town in northern Italy in the Veneto region). Libeskind explains:

The three lessons that I have offered here are the three lessons of architecture: (a) reading architecture, and its equivalent, the reading machine; (b) the lessons in the present remembering of architecture,

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<sup>113</sup> Libeskind's tenure at Cranbrook was from 1978 – 1985. The exhibition catalogue of the Venice Biennale names as authors of the Three Lessons: Daniel Liebeskind, Donald Oster, Karl Frederickson, Jim Cooper, Sixto Beltrandy, Ken Fukushima, Hani Rashid, Lori Rubeling, Ross Yerian, Thomas Han, Frank Fantauzzi, Hal Laessing, Tom Bish, Koichiro Tanaka and Lovorka Knezevic (1985, 164). Some of Libeskind's students, amongst others, were Donald Bates, Raoul Bunschoten, Karl Chu, Ben Nicholson and Jesse Reiser. See 'Inventory of the Daniel Libeskind Papers, 1968-1992,' held at Getty Research Institute, Research Library, Ref Nr.. 920061.

and the memory machine; (c) writing architecture, and its equivalent, the writing machine. So these are pieces of metaphysical equipment, because they don't really do anything, they are in another realm.<sup>114</sup>

Libeskind's student Raoul Bunschoten suggested in his 1985 essay 'Wor(l)ds of Daniel Libeskind: Theatrum Mundi/ 'Three Lessons in Architecture' that the machine trilogy is inspired by the meta-mechanical and imaginary interpretation of some medieval machines famous for their ingenuity.<sup>115</sup> The 'architecture thus formed has ancient predecessors and could be called mythopoetic. Daniel Libeskind is a re-inventor.'<sup>116</sup> In fact, the *Reading Machine* is an architectural interpretation of Agustino Ramelli's *Carroussel* (1588), the Memory Machine of Giulio Camillo's infamous *Memory theatre* (1532) and Jonathan Swift's *Lagado Word Machine* (1726) at the Grand Academy of Lagado served as a template for the *Writing Machine*. Only by the subtlest of references in the Biennale text are they linked to their medieval predecessors.<sup>117</sup> The relevant passages from Libeskind's text are quoted here:

Lesson A: Reading Architecture = Reading Machine

Teaches an almost forgotten (medieval) process of building, a process which is in its own way not yet fully unfolded in Architecture. Like the medieval monastery out of which the Reading Machine<sup>118</sup> emerged, the method of construction and the technique of understanding bring about a revolution of architecture's *techne* which coincides with the movement of the text as it propels. As a place of intersection between archaeological reconstruction (Ramelli, Palmonova, military engineering) and the will to power it discloses (metaphysics, monasticism, ideology) the Reading Machine reveals the tautological reality of the architectural text.

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<sup>114</sup> Libeskind 1991, 38.

<sup>115</sup> Raoul Bunschoten 1985.

<sup>116</sup> Bunschoten 1985, 84.

<sup>117</sup> For a profound analysis of Libeskind's *Three Lessons*, see Ioannidou 2010.

#### Lesson B: Remembering Architecture = Memory Machine

Consists of that which can still be remembered in Architecture. As a historical program the ten Biennale sites have been filtered through Giulio Camillo's Memory Theatre. The Memory Machine<sup>119</sup> consists of the backstage – only the spectacle takes place outside of it. ... Made of wood are also the 18 subordinate spectacles, which include the “cloud machines”, the “wave machine” as well as the “schizophrenic forum.”

#### Lesson C: Writing Architecture = Writing Machine

Teaches the artless and scienceless making of Architecture. As a fully engaged project this machine industrializes the poetic of Architecture and offers it as a sacrifice to its own possibilities of making a text. ... Since this Writing Machine<sup>120</sup> processes memory and reading material, it takes the ten Biennale projects into an exact account. ... The four sides of this “Orphic” calculator or probability computer prognosticate the written destiny of Architecture whose oblivion is closely associated with Victor Hugo's prophecy. The four-sided cubes work in the following Swift-ian manner:

Side 1: the City as a Star of Redemption is refracted and congeals into a “boogy-woogy” like constellation.

Side 2: is a metallic reflection which shatters and disrupts the spatial-mathematical order of the 49x4 sides.

[There is no mention of Side 3 in the 1985 Venice Biennale text.]

Side 3: consists of a geometric sign which points to a graphic omen or architectural horoscope.<sup>121</sup>

Side 4: enumerates the 49 saints who accompany the detached pilgrim in order to care for his unerasable vulnerability.

Thus the oppositions and complimentary reciprocities which glide through the whole constitute a ‘destabilised technology’ which would break-up the mechanism instantly if the computerised controls (28 handles) weren't there to keep it stable. ... The seemingly random

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<sup>118</sup> The Reading machine is dedicated to Petrarch.

<sup>119</sup> The Memory Machine is dedicated to Erasmus.

<sup>120</sup> The ‘Writing Machine is black and throws a gleam which is dedicated to Voltaire’ (Libeskind 1985, 168).

<sup>121</sup> The text for ‘Side 3’ is taken from Libeskind 1991, 55.

relations are generated by an extremely sophisticated system which consists of 2,662 parts, most of them mobile.<sup>122</sup>

In order to provide a better understanding of the relations between Libeskind's machines and their mediaval predecessors it is worth explaining their original purposes.

The *Reading Machine* was based on the book wheel, a device common in monasteries or universities for the reading of heavy books. Equipped with such a wheel Agostino Ramelli wrote in *Le diverse et artificiose machine* (1588), 'a man can see and turn through a large number of books without moving.'<sup>123</sup> As Jonathan Sawday observes in his book *Engines of the Imagination: Renaissance Culture and the Rise of the Machine* (2007) 'it answers to the scholar's dream of the machine that will read, digest, and process vast amounts of text on his or her behalf.'<sup>124</sup>

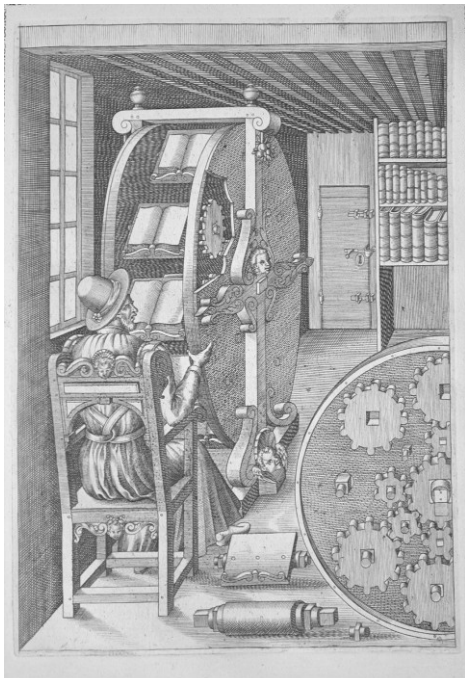


fig 1.30 Agustino Ramelli. *Carroussel*. 1588.

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<sup>122</sup> All three passages are quoted from the original Biennale text [underscore by author; italics in original]. See Rossi 1985. vol. I, p. 164-168.

<sup>123</sup> Ramelli 1588, 508.

<sup>124</sup> Sawday 2007, 111.

The *Memory theatre* was constructed with obsessive ingenuity in Venice by Giulio Camillo. The classical art of memory – to lend order to memory – used ‘places’ and ‘images’ for mnemonic purposes. According to Frances A. Yates, Camillo’s contribution to the art of memory was to construct a type of architectural mnemonic by systematically arranging memory places and thus the connotation with a theatre is not farfetched.<sup>125</sup>

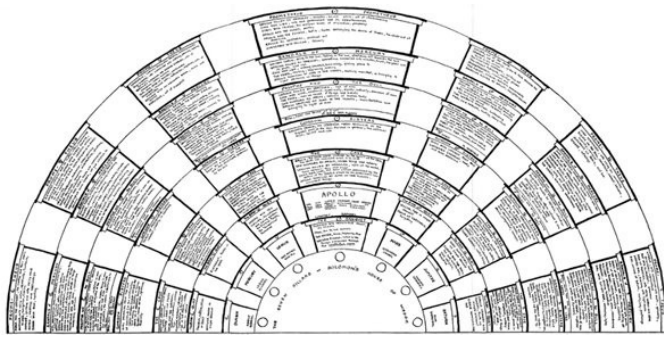


fig 1.31 Giulio Camillo. *Memory theatre*. 1532.

Although the object itself was just large enough to accommodate two people at once it was referred to by Viglius and his contemporaries as an ‘amphitheatre.’ Camillo adopted the classical architecture of the Vitruvian<sup>126</sup> amphitheatre for his memory theatre. [In] Camillo’s theatre the normal function of the theatre is reversed.<sup>127</sup> The spectator thus is located in the place of the stage. In his book *L'idea del Teatro*<sup>128</sup> (1550) Camillo explains that the theatre ‘rises in seven grades or steps, which are divided by seven gangways representing the seven planets. ... and since in ancient theatres the most distinguished person sat in the lowest seat, so in this Theatre the greatest and most important things will be in the lowest place.’<sup>129</sup> After inspecting the theatre in 1532 in Venice Viglius Zuichermus writes to Erasmus that it is ‘a work of wonderful skill, into which whoever is

<sup>125</sup> Yates explains in her book *The Art of Memory* (1978) that Camillo’s ‘theatre is a system of memory places ... it performs the office of a classical memory system (148).’

<sup>126</sup> In Vitruv’s description of the classical Roman theatre the auditorium is divided by seven gangways and the upper classes are sat at the lowest seats (Vitruvius 1999 Lib. V cap. 6).

<sup>127</sup> Yates 1978, 141.

<sup>128</sup> This short book was published posthumously in Florence and Venice based on a manuscript of Camillo’s friend and disciple which was produced in the year before Camillo’s death in 1544 in Milan.

<sup>129</sup> Camillo 1550, 14.

admitted as spectator will be able to discourse on any subject no less fluently than Cicero.<sup>130</sup>

The *Writing machine* depicted in Jonathan Swift's *Gulliver's Travels* (1726) would hold equal fascination for the augmentation of human capacities through machines. As David Porush observes what Swift allows Gulliver to witness on his travels at the Academy of Lagado is most certainly 'one of the first literary uses of the machine as metaphor.'<sup>131</sup>

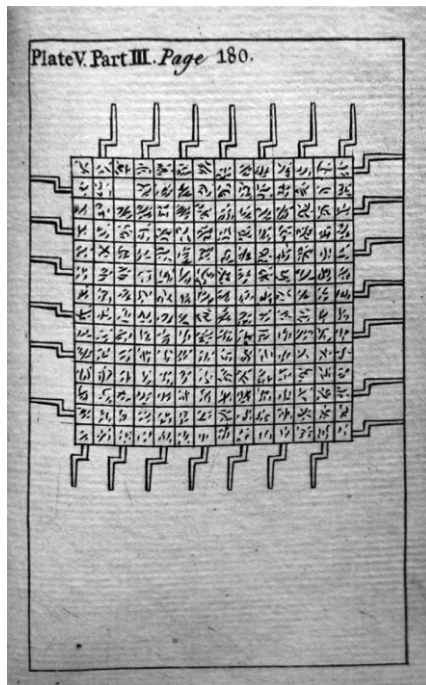


fig 1.32 Jonathan Swift. *Lagado Word Machine* at the Grand Academy of Lagado. 1726.

The *Lagado Word Machine* is presented to Gulliver by a member of the academy. The scientist who claims to have devised the machine explains that it will assist everyone in writing 'books in philosophy, poetry, politics, law, mathematics, and theology, without the least assistance from genius or study.'<sup>132</sup>

He then led me to the frame, about the sides whereof all his pupils  
stood in ranks. It was twenty feet square, placed in the middle of the

<sup>130</sup> Allen, P. S., Allen, H. M. and Garrod, H. W. (ed.) 1906 [1538]. *Opus epistolarum Des. Erasmi Roterodami*. Oxford: In Typographeo Clarendoniano. vol IX. p 479.

<sup>131</sup> Porush 1985, 6.

room. The superficies were composed of several bits of wood, about the bigness of a dye, but some larger than others. They were all linked together by slender wires. These bits of wood were covered, on every square with papers pasted on them, and on these papers were written all the words of their language in their several moods, tenses, and declensions; but without any order. The professor then desired me “to observe; for he was going to set his engine at work.” The pupils, at his command took each of them hold of an iron handle, whereof there were forty fixed round the edge of the frame; and giving them a sudden turn, the whole disposition of the words was entirely changed. He then commanded thirty-six of the lads, to read the several lines softly, as they appeared upon the frame; and where they found three or four words together that might make part of a sentence, they dictated to the four remaining boys, who were scribes. This work was repeated three or four times, and at every turn, the engine was so contrived, that the words shifted into new places, as the square bits of wood moved upside down.

Six hours a day the young students were employed in this labour; and the professor showed me several volumes in large folio already collected, of broken Sentences, which he intended to piece together, and out of those rich materials to give the world a complete body of arts and science...

The fascination of these machines lies in their potential to augment human capacities through technology. Their spirit would live on in Libeskind's next projects.<sup>133</sup> On their way to architectural mythology the machines transcended their material existence when they were destroyed by a fire in 1987.<sup>134</sup> Not unlike in the great mythologies, the object of desire is unattainable, or it vanishes and all traces disappear.

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<sup>132</sup> Swift 2010 [1726], 184.

<sup>133</sup> In 1987 Libeskind won the first prize in the last city-planning competition of Berlin's IBA series with his *City Edge* project. “The details of this scheme are a refinement of the architecture of the “machines.” (Cook and Llewellyn-Jones 1991,123).

<sup>134</sup> The machines were due to be exhibited at the Palais Wilson in Geneva when they were destroyed by fire. Following a long battle with his insurance provider, Libeskind was able to negotiate compensation for the machines which in turn funded the ‘Line of Fire’ project (1988) at the International Labour Organization

## Deconstruction and meaning of the machines

As Ersi Ioannidou suggest in her text 'Humanist Machines' Libeskind's *Three Lessons in Architecture* can be understood as a design experiment informed by the humanities. Libeskind's project implied the deconstruction of architecture's fundamental epistemological standards by retracing 'the narrative of modern Western architecture and its means of production.'<sup>135</sup> In his role as Biennale curator Aldo Rossi observed that for Libeskind, 'one of the most committed architects in this exhibition, architecture is even destroyed, upset, deprived of its image in order to be then recomposed in these machines ...'<sup>136</sup> In introducing the project Libeskind explained that the proposal had taken on 'the form of participatory engagement with three large machines [and] ... the public itself is involved with creating and interpreting Architecture in its broad social cultural and historical perspective.'<sup>137</sup> This project offered a way to learn new standards and reconstruct the image of architectural design practice.

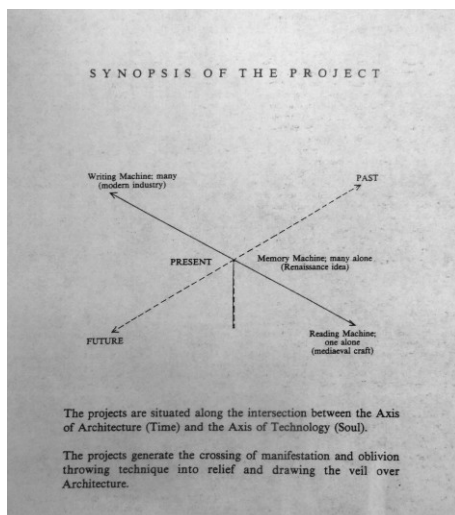


fig 1.33 Synopsis of the *Three Lessons* project.

Libeskind was involved in the greater Deconstructivist project that maintained that architecture shared the major structural features of language, in that it was organised by grammatical structures, and constructed meaning through syntax. But as the linguistic

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(ILO) in Geneva whose iconography would inform the extension to the Jewish Museum. See Libeskind 1988.

<sup>135</sup> Ioannidou 2010, 81.

<sup>136</sup> Rossi 1985, 14.

<sup>137</sup> Rossi 1985, 164.



studies of the 1970s and 1980s had shown, the meaning of text could not be determined by an author alone, as it would always be overlaid by individual memory, cultural practice and references. Lebbeus Woods recollects how some Deconstructivists had been grappling with the problem of meaning in language conveyed to architecture:

Peter Eisenman and the circle of architects and critics gathered around him, applied this to architecture, with the consequence that the “meaning” of architecture – symbolically and in terms of human purposes – was in their view not to be found in either the architects’ or their clients’ intentions ... form does not follow any a priori function but has autonomous existence that must, in the end, be “read” on its own terms.<sup>138</sup>

Such a reading of architecture shifts the attention away from the architect to the role of the observer, installing the architectural product as a communicative mechanism between them. Despite staying clear of any reference to cybernetics - the theoretical model developed specifically to describe the reciprocal relations between man and machine - Libeskind is overlapping the mechanic working of the machine with the syntactical structure of language. In comparing the way we read and imagine text with the way we read and imagine architecture, Daniel Libeskind installed the machine as a metaphor that could exist in both worlds. According to Lebbeus Woods the principal doctrine in Libeskind’s Deconstructivist attack on architecture’s fundamentals was ‘the idea that architecture must be read, that is, understood, in the same way as a written text.’<sup>139</sup>

### **Thaumaturgic qualities of machines**

Libeskind’s machines were unrelated to concerns of efficiency. Instead these machines, due to their medieval origins – can be related to a realm that Tzonis and Lefaivre have described as ‘mathematical magic’ in their essay ‘The Machine in Architectural

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<sup>138</sup> Blog entry ‘Libeskind’s Machines’ on <http://lebbeuswoods.wordpress.com/2009/11/24/libeskinds-machines/>; accessed 24/09/2010.

<sup>139</sup> Ibid.

Thinking.’<sup>140</sup> An important category of the experience of art in the Middle Ages the aim of automata, ‘thaumaturgic’ machines or ‘mirabilia’ ‘was to overwhelm the spectator with awe in the contemplation of the hidden powers at work in the world.’<sup>141</sup> The *Three Lessons*, like their medieval counterparts, offer for architectural thought to productively incorporate, rather than exclude, the spiritual and mythical knowledge of the past; reflecting an attitude that generally differs from the utilitarian outlook of modern technology. As imaginative mechanism, the machines manipulate ideas of a world that is not outside of our mind but inside of it. ‘The mind that wonders how it grew into this world and how the world grows into it ... is indeed a ‘windowed’ mind’ writes Raoul Bunschoten in his essay on Daniel Libeskind’s architectural machines. Here, Bunschoten paraphrases Viglius Zuichermus, who in reporting to Erasmus of Camillo’s exceptional *Memory Theatre* writes: ‘He calls this theatre of his by many names, saying that it is a built or constructed mind and soul, and now that it is a windowed one.’<sup>142</sup>

Libeskind’s retro-designed machines have entered the mind both as exhibited objects and through their mythologies that have been conveyed through oral history and literature. Despite – or because of – their deeply conceptual design, metaphoric description and unfortunate disappearance the machines have acquired mythopoetic and thaumaturgical qualities. Libeskind’s ambition for the machines to engender ‘participatory experiences,’ physical human interference with the machines, seems to have remained unfulfilled. However, as with their medieval predecessors, the motor of the *Three Lessons* is the human body. And only through the activation of the machine by human activity could their mechanical performance initiate a truly imaginary creation of remembered and desired spaces in a mind that is a window to the world.

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<sup>140</sup> Tzonis and Lefaivre 1985, 18.

<sup>141</sup> On medieval mirabilia machines ‘produced by artists and artificers for entertainment and display’ see Camille, Michel. 1989. *The Gothic Idol, Ideology and Image-Making in Medieval Art*. Cambridge: Cambridge University Press. p 244 ff. One such machine is for instance the *mechanical organ* of Michele Todini (or Todino, a famous virtuoso on the bagpipe). Constructed mid-seventeenth century it was an assemblage of numerous freestanding string and wind instruments. These instruments were not connected physically but nevertheless sounded sympathetically. As Joseph Rykwert observes, ‘in its quasi-magical working this mechanical organ combined the attributes of a natural and an artificial object ... [and] often astonished even the uninitiated (1992). For details on the mechanical organ see Todini, Michele. 1676. *Dichiarazione della Galleria Armonica*. Rome; Kircher. Athanasius. 1673. *Phonurgia Nova sive Conjugium Mechanico-Physicum Artis et Naturae*. Kempton. p 167 ff.

## c1 | Conclusion

Machines allow architecture to engage with new spirits, belief systems or technological paradigms. The nuanced influences of machines reach beyond their mechanical capacities. In times when architectural design was guided by spiritual belief systems and geometrical harmony, the emerging science of mechanics became a disruptive force. Due to increasing scientific practice, the spiritual verification of architectural design became unfashionable and empirical verification and analytical backing of architectural thinking gained currency. Architecture's entanglement with machinic efficiency grew tighter, and the fascination with the control of the human body through deterministic and optimisation strategies gradually began to inform the design of buildings. The machine became to be seen as a means to transcend human limitations. On the one hand the machine imported into architecture tactics of rationalisation and standardisation, while on the other hand it imported new methods of expression.

The idealised autonomy and deterministic behaviour of mechanical systems provided the pretext for modernity's affirmation of the machine. Although machines as *metaphors* were en vogue ['Une maison est une machine à habiter'],<sup>143</sup> thanks to László Moholy-Nagy machines were introduced as *design medium*. However, during the following dark years of World War II, machines lost their appeal as conceptual media.<sup>144</sup> Visions of machine architectures, performative buildings and living cityscapes resurfaced when architects in the 1960s began to address architecture's incapacity to respond to rapidly changing socio-cultural conditions. From Archigram's architecture-as-event to the technomorph architectures of Neil Denari and Wes Jones, the machine was installed once again as a more or less sublime inspiration for architectural designs. The most explicit use of machines as architectural medium, Libeskind's *Three Lessons in Architecture* shown at the Venice Biennale in 1985, proposed investigating the relationship between architecture and language. The deconstruction of architecture's fundamental epistemological standards in architecture's digital spring relied on the imaginary workings of retro-mechanical machines. Thus the machines signalled the end of the ambivalent relationship of 1980s

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<sup>142</sup> Tzonis and Lefaivre 1985, 84.

<sup>143</sup> LeCorbusier 1946 [1923], 100.

<sup>144</sup> Due to cyberneticians like Norbert Wiener or Alan Turing moving from military to academic environments, cybernetics, the science of machine control, which was instrumental to effective production and operation of war machines, only entered wider cultural discourse after WWII.

architecture with technology and of its romantic allusions to technomorph ‘machine-architecture,’ and the beginning of architecture’s liberation from its reliability on stable materials and inertia—‘not only in the transformation of static materials into things kinetic but also the dynamization of the perception of space itself.’<sup>145</sup> Inasmuch as architecture has affirmed the deterministic capacities of machines, it could not remain unaffected by its expressive forces.

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<sup>145</sup> Salter 2010, 82.



## c2 | Softer architectural machines

Experimental medium in architectural design – Convergence of computation and machine – Biologisation of architectural machines

For each type of machine we will pose a question, not about its vital autonomy – it's not an animal – but about its singular power of enunciation.

Felix Guattari<sup>146</sup>

### Introduction

From experimental devices to interactive installations, architectural machines often import progressive technologies into the realm of architectural design.<sup>147</sup> As a consequence, architectural machines are catalysts for paradigm shifts in theorization of technology in architecture. Recent developments, such as influences from computation technologies or bio-inspired design tactics, have contributed to a change from understanding the architectural machine as a mechanically-deterministic medium, to seeing it as an autonomous entity equipped with sensorial and reactive capacities that enable it to engage more intensely with human beings. Theoretical and technological developments such as autonomous behaviour or morphogenetic design warrant completely novel design approaches and often require the development of new construction methods. The appearance of new machines softened by technology often alludes to the anatomies and behaviours of natural bodies. Internal functions and protocols are inspired by interdependencies and hybrid functions of organic metabolisms.<sup>148</sup> Materials, morphologies, performances and behaviours are becoming soft, pliable, flexible and non-descriptive. In as much as theorization of technology has changed from functional

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<sup>146</sup> Guattari 1995, 34.

<sup>147</sup> See 'Novel Tools and Heuristics' in Fox and Kemp 2009, 180-184.

<sup>148</sup> In architectural machine design structural and functional analogies are increasingly being applied for bio-inspired design of structures, actuators, sensors and control units, see Beesley 2010a+b, Wihart 2005; 2010. Such ascriptions have historical precedents. See Steadman 2008 [1978] and Forest de Belidor's account of analogies between steam engines and animals in 'Organic mechanisms,' Fernández-Galiano 2000, 145.

outlook to more open-ended protocols, architectural machines have evolved from being isolated mechanical entities to networked and/or hybridised assemblies.

### *Chapter overview*

In Chapter 1 I discussed some of the reasons *why* machines have become a defining mechanism for architectural concepts, this chapter explores *how* machines are being employed and developed as medium in architectural design. The first section discusses how architectural machines manifest themselves – from small devices to installations spanning entire rooms. Sections 2 and 3 re-trace the theoretical and technological developments that emancipated architectural machines from their mechanical past. In section 2 I discuss the convergence of the machine with computational strategies around concepts laid out in the science of cybernetics, which introduced protocols of autonomy and interaction to architectural machine design. Section 3 looks at how the interactive paradigm (which was – or still is – predominantly software based) has been taken further by incorporation of bio-inspired design strategies.

# s1 | Experimental medium in architectural design

Experimentation – Invention – Manifestations of architectural machines

In his book *Experimental Architecture* (1970) Peter Cook maintained that in a discipline that values freedom of expression, experimentation is a vehicle for transgressing the norm.<sup>149</sup> For speculations about architectural conditions architects employ methodologies as diverse as drawing, modelling, programming, writing or model making. While these methodologies tend to abstract space, materiality, scale or function in one way or another, architectural machines, in their various manifestations as device, apparatus, wearable prosthetic, automata, self-regulated device or interactive installation are allowing architects to explore things dynamic and transformable. Due to its physical nature there are smaller degrees of abstraction in architectural machines. It could be said that machines are more actual than simulated. Machines might be developed by going through design phases in the form of drawings, simulations or form part of architectural narratives. Cook has pointed out that ‘the idea of starting with a machine that really has to work and circuitously moving in on to the building itself has the great virtue of keeping the thinking-to-designing pressure up the whole time ...’<sup>150</sup> As physical medium the architectural machine encourages experimentation with materials, technologies, construction methodologies (often from outside the field of architecture) to inform design practices and a physical understanding of architecture.<sup>151</sup> As such, architectural machines are inevitably and intrinsically expressions of an attitude towards technology. Unsurprisingly, machines are often used as generative design media in their own right.

## Experimentation

The practice of experimentation is a prevalent pre-conditions that informs the design and making of architectural machines. According to French art historian Henri Focillon an

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<sup>149</sup> Cook 1970; especially chapter 2 ‘Experiment is an inevitable’ pp 30-68.

<sup>150</sup> Cook in Hawley and Lim 1995, 13.

<sup>151</sup> Michael Fox and Miles Kemp maintain in their book *Interactive Architecture* that experimentation within the discipline of architecture often coincides with the use of advanced technologies (2002, 178).



important condition of the experiment in the context of creative practices is its power to advance craftsmanship and technique. Focillon defined the experiment as ‘an investigation that is supported by prior knowledge [and] conducted with intelligent reason, and carried out in the realm of technique.’<sup>152</sup> The spirit of experimentation encourages trial and error. In architectural design, however, the role of experimentation is very different to the understanding of ‘experiment’ in its scientific form, where it is used to confirm or refute rules for certain assumed conditions on the basis of the relation between hypothesis and experiment, as Albert C. Smith points out in his book *Architectural model as machine* (2004).<sup>153</sup> As Peter Cook notes in *Experimental Architecture* (1970) it is difficult to define experiment in the architectural sense.<sup>154</sup> In architecture, rules and references against which the outcome of an experiment could be judged are located in bodies of knowledge, such as structural theory, material sciences or fabrication, disciplines which are ‘a mere technical backup and have limits as support to a theory of architecture.’<sup>155</sup> As proponent of the imaginary potential of technology architectural machines can mediate between disciplines and practices. In importing technologies, strategies and structures from other disciplines into architectural discourse, machines instil dynamics not only in their physical environment but also through their theoretical reality. The speculative potential of a machine experiment might not be to find out more about the technology of the machine but how its technologies can facilitate innovative architectural speculations.

## Invention

As Gerald Raunig points out the Latin term *machina* ‘holds the technical meaning of apparatuses, frames, devices as well as the psychosocial meaning of trick, artifice, deception.’<sup>156</sup> Raunig goes on explaining that ‘this ambiguity is most adequately transported in English by the word “invention” (from Latin *invenio*, meaning “to find, to come upon”): the machine is an invention, an invented device, and it is an “invention” as

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<sup>152</sup> Focillon 1948, 9.

<sup>153</sup> Smith 2004, 115.

<sup>154</sup> Cook 1970, 16.

<sup>155</sup> Cook 1970, 16.

<sup>156</sup> Raunig 2010, 36-37.

an invented story, as a deception, as a machination. Technical innovation and inventiveness blur together here along the two mutually merging lines of the meaning of machine.<sup>157</sup> In *The Origins of Feedback* (1970) Otto Mayr points out that in Antiquity technological innovations served not only practical purposes but also enjoyment, curiosity and often pure delight of innovation.<sup>158</sup> Hero of Alexandria's treatise *Pneumatica*<sup>159</sup> (c. 10–70 AD [1851]) contained description of temple doors (fig 2.01) which were operated automatically by pneumatic means.<sup>160</sup> Vitruvius' much cited *De Architectura* contained in Book X, Chapter 8 a description of the water organ (fig 2.02) and ascribed it to Ctesibius.<sup>161</sup>

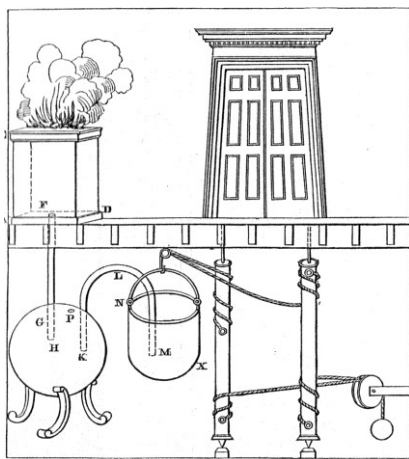


fig 2.01 Temple Doors opened by Fire on an Altar.<sup>162</sup>

Included in Hero of Alexandria's *Pneumatica*, the self-opening temple doors are amongst a collection of automated devices driven by water or air pressure.

<sup>157</sup> Gerald Raunig explains in his book *A Thousand Machines* (2010) that the term *machina* has appeared in Latin since Plautus and Ennius in the early second century B.C. and increasingly during the imperial era and Late Antiquity. It is thought that the word initially derived from the Doric vocabulary of the colonists of lower Italy. The Latin *machina* thus assumes all the meanings of the Greek *mechané* (the Doric word, already relatively close to the Latin, was *machaná*) (36). The Etymology of *machine* also reveals close linkages with the realm of making and invention. The Doric Greek μηχανή (*mēkhanē*) means 'contrivance' and comes from μάχος, μέχος (*mēkhos*) meaning 'device, assistance, way' (ODEE, 543).

<sup>158</sup> Mayr 1970, 26.

<sup>159</sup> The *Pneumatica* is a collection of automated devices driven by water or air pressure, considered to have been written by Hero of Alexandria, a pupil of Ctesibius. Both were famous for their skills in the invention of pneumatic and hydraulic devices and instruments, such as water clocks, water-organs and devices for lifting water. See Woodcroft 1851.

<sup>160</sup> Woodcroft 1851, 59.

<sup>161</sup> See Vitruvius 1999, p126 for the translation of the original text and p306 for commentary and illustrations of the water organ.

<sup>162</sup> Woodcroft 1851, 59.

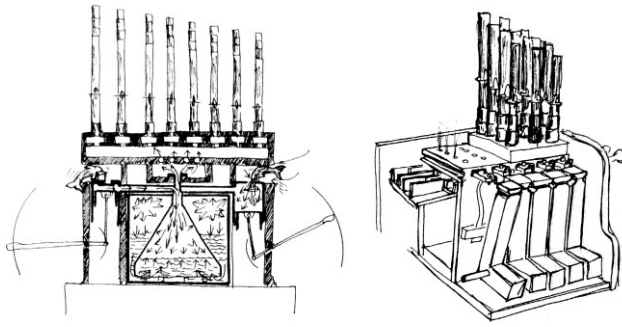


fig 2.02 Water organs of Ctesibius.

Vitruvius included the water organ in his *De Architectura*, Book X, Chapter 8.

Drawings in Vitruvius 1999, 306 based on reconstruction of organ found at Aquincum.

The organ is also testament to the ancient conception of technology as completely unrelated to concerns of efficiency. In his widely read book *An Inventive Universe* (1975), English philosopher of science Kenneth G. Denbigh points out that in contradiction of the proverb ‘necessity is the mother of invention ... an essential condition for inventiveness is *the absence of necessity*.’<sup>163</sup> Denbigh observes that one cannot speak of ‘genuinely new things coming into existence unless they are both different from and not necessitated by anything existing beforehand.’<sup>164</sup>

## Manifestations of architectural machines

As designed and constructed artefacts, architectural machines can manifest themselves along the trajectories of ideas – from initial gestation as device through to its full-scale realisation as installation.<sup>165</sup> However, these manifestations should not be considered to be mutually exclusive as installations often include devices, a mise-en-scène machine often has an experimental past, and so forth.

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<sup>163</sup> Denbigh, Kenneth G. 1975. *An Inventive Universe*. London: Hutchinson. p 153 [italics in original].

<sup>164</sup> *ibid.*, 153.

<sup>165</sup> Compare with Anthony Dunne’s observations about various manifestations of design output, including prototypes, props, models or installations (2005, 84-98).

## *Devices*

The creation of architectural machines brings together technology, craftsmanship, technique and the emergence of meaning through performance. In academia the fascination with the autonomous performance unrelated to concerns of efficiency is often a central aspect of architectural machine making. But sometimes machines take on the form of devices, and it is worth making that fine distinction in terminology.

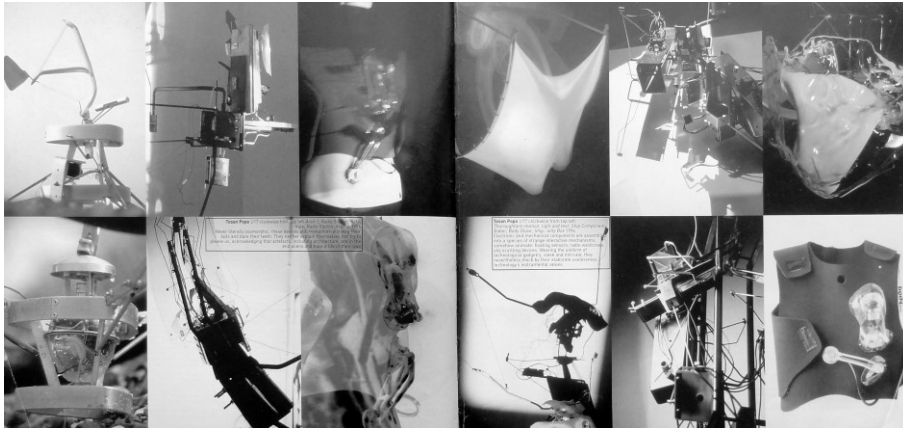


fig 2.03 Collection of devices created at the Barlett School of Architecture.

For architect and educator CJ Lim, device making is an essential part of architectural education because the device is freed of purpose and servitude but nevertheless still able to embody the mannerisms and characteristics of a machine. In his book *Devices: a Manual of Architectural + Spatial Machines* (2006) CJ Lim states that '[p]erhaps the *function* of [...] devices is instead to manipulate phenomena in the same way that architecture does – using space, time, sound and materiality to interact with its audience on a performative relationship. The diminished physical and financial scale, coupled with disconnection from purpose, makes device making a breeding ground for invention and spatial possibility.'<sup>166</sup>

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<sup>166</sup> CJ Lim 2006, 16 [italics in original].

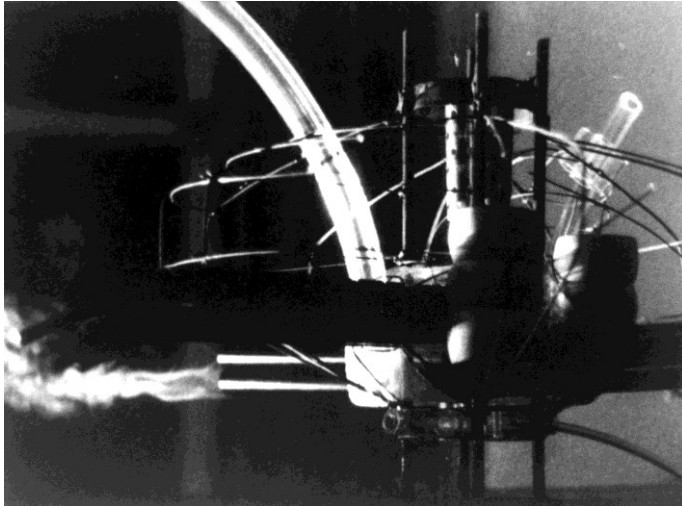


fig 2.04 Coop Himmelb(l)au. 02.01 *Städte, die pulsieren wie das Herz* [Cities pulsating like the heart]. 1967.  
Device made from metal wire, transparent acrylic and PVC tubing. Also see *Herz Stadt – der weisse Anzug* [Heart City – the white suit]. 1969; in c4. s3 Pneumatic Bodies.



fig 2.05 Mark Fisher and David Harrison. *Automat*. 1969.  
Low-pressure structure capable of expanding/ contracting at a ratio of 80:1. Multi-cellular arrangement with internal bracing and external air hoses. Fisher and Harrison describe the device as a model for '[a] pneumatic environment enclosure system whose size and shape are indeterminate until controlled by the user. Large enclosures can be grown or repacked from small bundles in response to instructions.'<sup>167</sup>

For instance, in the 1960s and 1970s when pneumatics<sup>168</sup> was a popular and futuristic medium enabling architects to combine experimentation with the socio-innovative

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<sup>167</sup> Cook 1970, 65.

<sup>168</sup> Pneumatics is 'the branch of physics which deals with the mechanical properties (as density, elasticity, pressure, etc.) of air or other elastic fluids or gases' (OED XI, 1099). More specifically, pneumatics in a technological context is dealing with the application of pressurized gas in order to affect mechanical motion. In architecture the term pneumatics tends to refer to lightweight structures constructed from pressurized membranes (Otto 1977).

potential of architecture,<sup>169</sup> Architectural Association students Mark Fisher and David Harrison produced a pneumatic membrane device that was conceived as an evolving or responsive structure.<sup>170</sup> The project exemplifies the innovative powers of architectural machine experimentation.

### *Mise-en-scène machine*

Architectural machines, as devices for interrogation of subjects such as relations between the biological world and architecture, human perception of space, etc., are often staged for display or performance. Chris Salter in his book *Entangled: Technology and the Transformation of Performance* (2010) discusses the staging of machines in the context of performative arts by borrowing the French term ‘mise-en-scène’ (French for ‘placing on stage’), which is predominantly used in performative arts, film and theatre.<sup>171</sup> In French the professional responsible for the ‘mise-en-scène’ is the director, called ‘le metteur-en-scène’ (French for ‘the stage setter’).<sup>172</sup> ‘Mise-en-scène’ is as much about storytelling as it is about stagecraft or the arrangement and instruction of actors, scenery and effects.

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<sup>169</sup> See Dessauce 1999 for an account of the connection between pneumatics as movement in experimental architecture and its socio-cultural imagination. The book presents projects for inflatable structures and furniture by the Utopie group, which was formed in 1968 by architects and sociologists (Jean Aubert, Jean-Paul Jungmann, Antoine Stinco, Hubert Tonka and Jean Baudrillard) to formulate a radical critique of architecture and everyday life.

<sup>170</sup> Cook 1970, 63.

<sup>171</sup> Salter 2010, 277.

<sup>172</sup> Salter has described Jean Tinguely’s 1960 performance event *Self-Destroying Construction No.1 - Hommage to New York* at the New York Museum of Modern Art (MoMa) as a ‘mise-en-scene machine.’ See Salter 2010, 277.

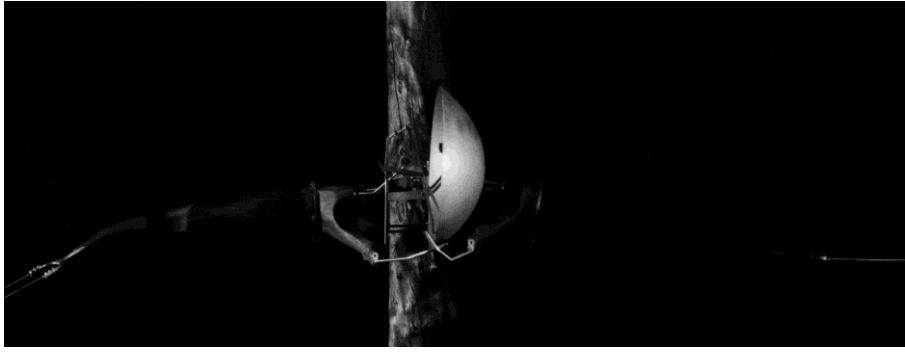


fig 2.06 Katie Davies and Emmanuel Vercruysse. *Prosthetic Mythologies*. 2007.

The site specific project was installed in Kielder Forest, Northumbria. While the newly planted forest shares ecologies similar to the forests of Scandinavia it shares none of its native culture and folklore. The project attempts to instigate and imbue the forest with new mythologies.

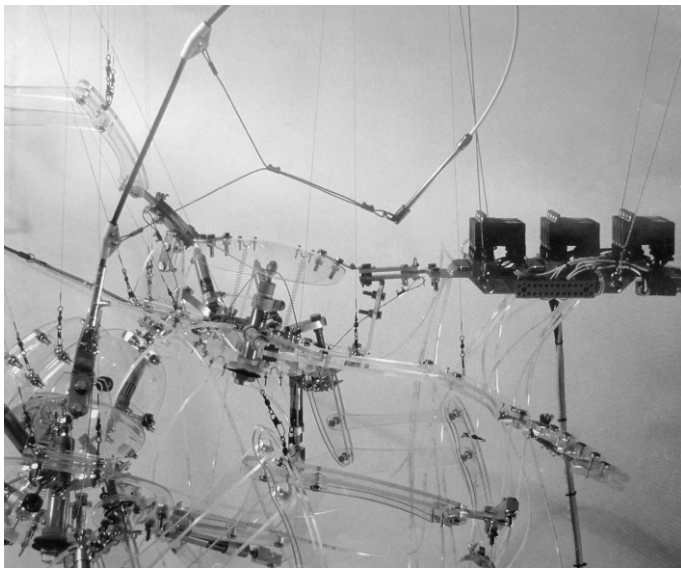


fig 2.07 Neil Tomlinson. *Thorax Cybernation*. 1994.

Described as self-designing temporal space machine by CJ Lim, the project investigates the interplay between physical structure and its potential to produce an array of unpredictable structures.<sup>173</sup>

When architects design architectural machines and consider them for public display, they invariably stage them, exploiting the theatrical potential of machinic performance. In doing so, they become the directors of their machine and the machine's subsequent encounters with human beings. The architectural mise-en-scène machine might be a stand-alone object – physically externalised and isolated – but it is nevertheless a participant of imaginary worlds.

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<sup>173</sup> Lim 2006, 202-205.

## *Installation*

While the *mise-en-scène* machine tends to manifest itself as a stand-alone performance, architectural machines can also be part of larger scale assemblies in a medium that has become to be known as installation.<sup>174</sup> Predominantly explored on the threshold between art and architecture installations have developed over the last few decades as a rich and increasingly diverse art practice that is influenced by early site-specific sculptures, happenings, and conceptual and performance art. As Sarah Bonnemaïson and Ronnit Eisenbach explain in their book *Installations by Architects* (2009) due to their participatory appeal – inviting the public to touch, enter and experience the work – installations have become a popular vehicle for teaching and research in architecture university programmes.<sup>175</sup> One example is Michael Williams' investigation into epistemological relations between the human body and objects. Designed and constructed in 1990 at the Cranbrook Academy of Art the installation *Necessary Frictions* uses a chair for interrogating how the human body 'comes to know itself ... amid the objects of the world ... [as] every objects presents itself as a particular configuration of resistance to the body'.<sup>176</sup>



fig 2.08 Michael Williams. *Necessary Frictions*. 1990.

A chair is the centre piece of an installation that investigates aspects of human interaction with objects involving sight and touch as mechanisms of inspection while recording these interactions via photographic film and as the inscription of movement in grease.<sup>177</sup>

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<sup>174</sup> Bonnemaïson and Eisenbach 2009, 14.

<sup>175</sup> Bonnemaïson and Eisenbach 2009, 14. On the use of installations in teaching and research, see Hoffman 1994 and Bonnemaïson, Eisenbach and Gonzales 2006.

<sup>176</sup> Williams in Hoffman 1994, 71.

<sup>177</sup> Williams in Hoffman 1994, 71ff.



The interrogation of human relations with the world has been extended dramatically with the emergence of interactive technologies.<sup>178</sup> Equipped with sensors, computing boards and kinetic actuators, interactive installations are enabled to react and interfere according to pre-programmed protocols. These installations can offer a degree of versatility and control that has been impossible previously to achieve by mechanical means alone. Some examples of installations composed of machinic components and enabled by sophisticated computational as well as construction, manufacturing and material technologies are Philip Beesley's *Hylozoic Ground* (2010) and Omar Khan's *Open Columns* (2007) projects. Beesley explains that the *Hylozoic Ground* project functions similarly to a living system, with embedded machine intelligence and dynamic material exchanges that allow human interaction to 'trigger breathing, caressing, and swallowing motions and hybrid metabolic exchanges.'<sup>179</sup>



fig 2.09 Philip Beesley. *Hylozoic Ground*. 2010.

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<sup>178</sup> For discussion of the term 'interactive' see c2. s2 Interaction with architectural machines.

<sup>179</sup> Beesley 2010a, 14.



fig 2.10 Omar Khan. *Open Columns*. 2007.

Architectural installations offer the opportunity to test concepts in a larger than human body format. In terms of scale, and often complexity, installations can certainly be considered to constitute the most ambitious foray into the mediation of space between technology and human beings. The installation as technologically mediated environment might not be a stand-alone-machine by definition, but its close alliance with the realm of machines is undeniable due to its composition of machinic components, devices, sensors, electronic relays, computing boards and actuators. The non-human movement and behaviour of installations infuses space with capacities and sensitivities associated with the living realm. Arguing that technology is moving from the background into the centre of installation concepts, Julie Reiss maintains in her book on *From Margin to Centre: The Spaces of Installation Art* (1999) that installations create ‘a reciprocal relationship of some kind between the viewer and the work, the work and the space, and the space and the

viewer.<sup>180</sup> The intensified reciprocation in interactive, responsive or adaptive environments can engage human beings, not only as viewers, but can inspire a multi-sensorial experience that ultimately engages, not only the eye, but the entire body with its architectural environment – not least because computation has been given its complimentary, active body in the corporeality of architectural machines.

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<sup>180</sup> Reiss 1999, xiii.

## s2 | Convergence of computation and machine

Conversations with architecture through machines – Negroponte’s Soft Architecture Machines – Interaction with architectural machines – Embedded computing and kinetic design

With the advent of computation around the mid-twentieth century, artistic interests in man-machine interactions were directed less towards the mechanical and more involved with processes and information communication. Movements such as *Arte Programmata*, as Umberto Eco and Bruno Munari named it, would embody an awakening desire for spontaneity, open systems and the convergence of artistic creation and machinic performance.<sup>181</sup> Histories of technologically augmented practices have situated the foundations of interactive work in the happenings and participatory artworks of the 1950s and 1960s.<sup>182</sup> According to American media theorist Margaret Morse, the concept of interaction became a ‘cultural novum’ in the early 1960s, in a technical as well as in a social sense.<sup>183</sup> Coincidentally, architecture’s long nurtured ‘machine’ metaphor was challenged as the idea of machines was blurred by incorporation of electronics and digital information processing strategies.<sup>184</sup> The emerging cybernetic paradigm would provide explanation models for processes, control and feedback of the flow of information between man and machines. Critically cybernetic thinking has introduced architecture to contemplating the machine as interactive. At the transition from the mechanical to the information age the mathematician Norbert Wiener articulated a coherent theory of cybernetics.<sup>185</sup> His book *Cybernetics: Or Control and Communication in the Animal and the*

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<sup>181</sup> Salter 2010, 303.

<sup>182</sup> Salter 2010, 305; where Salter draws reference to some of the many numbered art histories discussing backgrounds for interactivity: Wardip-Fruin and Montfort 2002, Huhtamo 1998, Shanken 1998 and Paul 2003 amongst others.

<sup>183</sup> See Morse, Margaret, ‘The Poetics of Interactivity’ in Malloy, Judy (ed.) 2003. *Women, Art, and Technology*. Cambridge, Mass.: MIT Press.

<sup>184</sup> One could succinctly state that *Newton machines* were superseded by *von Neumann machines*. Whilst Isaac Newton has laid the foundation for classical mechanics John von Neumann is accredited with being a founding figure of digital computing.

<sup>185</sup> Wiener is generally perceived as ‘the father of cybernetics’ (Spiller 2002, 46), but has himself acknowledged that the term cybernetics has been used by James Clerk Maxwell in a paper on feedback

*Machine* (1948) is still considered a conceptual breakthrough for the scientific community interested in the steering and control of complex human and machine systems and their interaction.<sup>186</sup> Wiener placed the control principles of artificial machines along those found in the natural world. His thesis posited that all animals (including human beings) can be described as machines that are controlled by feedback. Wiener argued that ‘the problems of control engineering and of communication engineering were inseparable and that they centred ... around the much more fundamental notion of the message whether this should be transmitted by electrical, mechanical or nervous means.’<sup>187</sup> W. Ross Ashby maintained in his seminal book *An Introduction to Cybernetics* (1956) that cybernetics is still ‘a “theory of machines,” but it treats not things but *ways of behaving*.’<sup>188</sup> In reminding us of Raunig’s epigraph, Ashby explains that cybernetics ‘does not ask “what *is* this thing?” but “*what does it do?*”’<sup>189</sup>

## Conversations with architecture through machines

Initially, Wiener’s intricate mathematical treatment of feedback, entropy and control theory was accessible to only a small percentage of artists and architects. But with the publication of *Human Use of Human Beings: Cybernetics and Society* in 1950, Wiener made his theories available to a wider public and cybernetics became a kind of ‘cultural mindset,’ in the words of art historian Edward A. Shanken.<sup>190</sup> Chris Salter observes that it was through a small handful of philosophers like Marshall McLuhan and Umberto Eco, curators, historians and impresarios like Jack Burnham, Jasia Reichardt, Frank Popper and Jon Brockman, artists such as John Cage, Nam June Paik, Robert Rauschenberg, Allan Kaprow, Nicolas Schöffer and Roy Ascott that cybernetics trickled down into the artistic mind.<sup>191</sup> Jasia Reichardt, curator of the groundbreaking London Institute of Contemporary Art exhibition *Cybernetic Serendipity* (1968) recalled in 2004, ‘at the time

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mechanisms, published in 1868 (Wiener 1948, 11-12). For a historical account of control engineering see Mindell 2002. For a history of feedback control reaching back to Hellenistic ages see Mayr 1970.

<sup>186</sup> Salter 2010, 307.

<sup>187</sup> Wiener 1948, 8.

<sup>188</sup> Ashby 1956, 1 [italics in original].

<sup>189</sup> Ashby 1956, 1 [italics in original].

<sup>190</sup> Shanken 2003.

<sup>191</sup> Salter 2010, 307.

computers had not revolutionized music, or art, or poetry, in the same way they had revolutionized science ... [but] with the advent of computers the world of art expanded beyond conventional boundaries.<sup>192</sup>

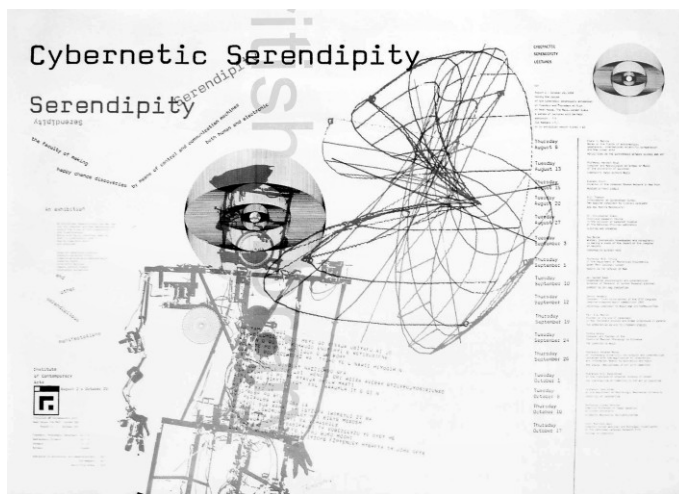


fig 2.11 Franciska Thamerson. *Cybernetic Serendipity*, exhibition poster. 1968.  
The groundbreaking exhibition at the ICA, London was curated by Jasia Reichardt.

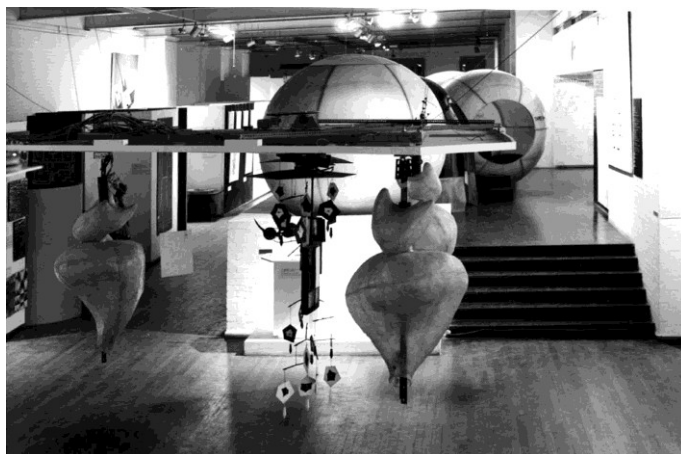


fig 2.12 *Cybernetic Serendipity*, exhibition view.  
Cybernetic Serendipity was one of the first machine-computer-art exhibitions. It featured a host of cybernetic environments, sculptures and remote controlled robots alongside computer-generated graphics, computer-animated films, computer-composed and played music and verse.

Machines in the art world would never be understood as ‘mechanical’ again. Cybernetic thoughts and ambitions became part of the popular imagination and their legacy survives today in our language (cyborgs, cyberspace, etc.). As in the arts, cybernetic thinking would

<sup>192</sup> Jasia Reichardt quoted in Bullivant 2006, 12.

enable designers and theorists alike to relate the human being to architecture in radically new ways. Eventually, architecture would be introduced to cybernetic thinking, most notably through the work of English psychologist and cybernetician Gordon Pask, English architect and influential educator Cedric Price and American architect Nicholas Negroponte.

In his chronology of technologies and theories that have shaped contemporary understanding of cybertechnology, *Cyber\_reader* (2002), Neil Spiller observed that through development from ‘first order’ to ‘second-order’ cybernetics, attention shifted way from Wiener’s focus on communication and control towards ideas of interaction which included the observer as part of the system.<sup>193</sup> Cybernetics acquired an anthropological position when machine actions were reflected through human action. It was Gordon Pask who sought to create machines and environments able to instigate meaningful interaction – or in his own words ‘conversation’ – with man.<sup>194</sup> Pask’s Conversation Theory was the basis for his *Aesthetically Potent Environments*, which featured machines that themselves became tools for understanding and exploring his conversation theory.<sup>195</sup> With reference to Pask’s involvement in Cedric Price and Joan Littlewood’s ambitious but ultimately unrealised *Fun Palace* project (1963-1974) Salter maintains that ‘Pask’s theatrical understanding of cybernetics as a dynamic conversation between spectators and performers coupled with the project’s desire to turn passive spectators into active shapers of their lived environment guaranteed that the *Fun Palace* would [...] play an essential role in the history of interactive environments.’<sup>196</sup>

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<sup>193</sup> Spiller 2002, 47.

<sup>194</sup> Pask 1969 and 1976.

<sup>195</sup> Spyropoulos 2007, 147.

<sup>196</sup> Salter 2010, 312.

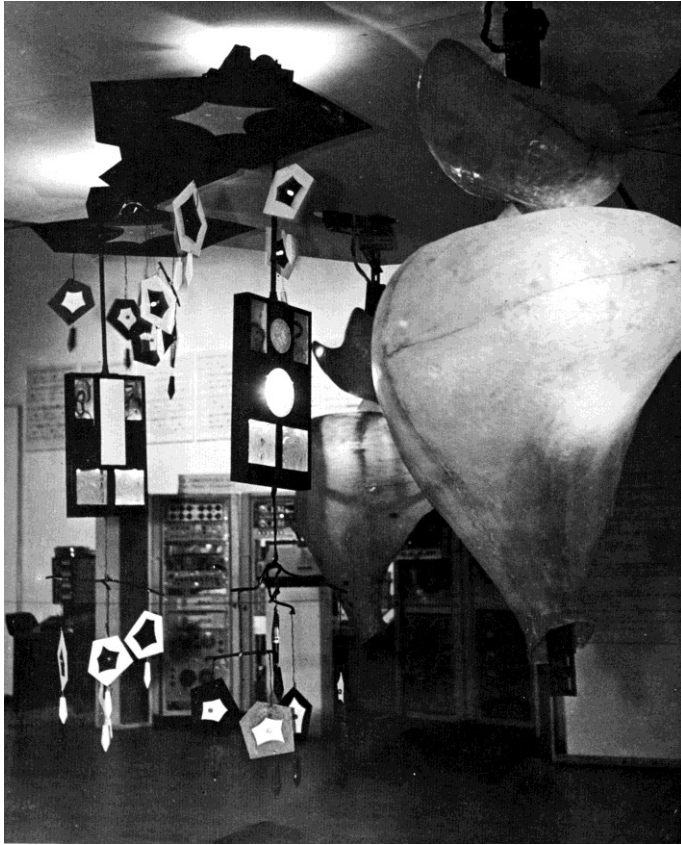


fig 2.13 Gordon Pask. Mobiles at Cybernetic Serendipity. 1968.

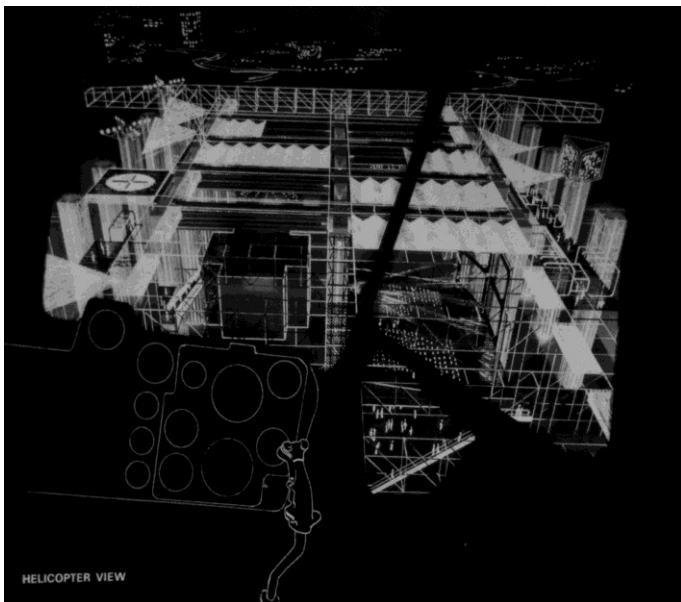


fig 2.14 Cedric Price and Joan Littlewood. *Fun Palace*. 1963-1974. Perspective drawing/ helicopter view.



*Interactive/ responsive/ intelligent/ smart ...*

The definition of the term 'interaction' is open to debate, and has come to refer 'to anything generally reactive or responsive' as Usman Haque laments.<sup>197</sup> Michael Fox and Miles Kemp note that the current terminology abounds with terms such as 'responsive architecture,' 'intelligent environments,' 'smart architecture' or 'soft space' and they clearly distinguish 'the physical and tangible' from the wealth of digital media projects that are in fact 'interactive' but cannot be considered 'interactive architecture.'<sup>198</sup> Fox and Kemp are drawing attention to Haque who explains that interaction must be circular, or else the system is merely 'reacting' and not 'interacting.'<sup>199</sup> Thus, a truly interactive system is a multiple-loop system in which humans engage in continual and constructive exchange with the system. Kas Oosterhuis, founder of the Hyper Body Research Group at the TU Delfts, proposes a bi-directional definition of interactive architecture where in its most sophisticated manifestation it is considered first 'the art of building relationships between built components and second, as building relations between people and built components.'<sup>200</sup> Designing responsive or interactive prototypes involves the contemplation of reciprocal anticipations of both humans and machines throughout the design process.

### **Negroponte's *Soft Architecture Machines***

Gordon Pask was a member of the 'Fun Palace Cybernetics Subcommittee' on the Fun Palace project at roughly the same time that he was working as a consultant to American architect Nicholas Negroponte's MIT based Architecture Machine Group.<sup>201</sup> The group, founded in 1967, also experimented with creating meaningful relations between humans and architecture through the agency of machines. In 1970, Negroponte published *The Architectural Machine: Toward a More Human Environment* where he announced 'a humanism

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<sup>197</sup> See Usam Haque's article 'Distinguishing Concepts: Lexicons of Interactive Art and Architecture' in Bullivant 2007, 26. The essay also highlights the intricacies of defining the conceptual framework for interactive architecture (without blurring it with artistic practices).

<sup>198</sup> Fox and Kemp 2009, 13.

<sup>199</sup> Haque 2006.

<sup>200</sup> Oosterhuis 2007, 4.

<sup>201</sup> Salter 2010, 310.

through machines.<sup>202</sup> In introducing the research aims of his group, Negroponte proclaimed to advance architectural design through the ‘intimate association of two different species (man and machine), two dissimilar processes (design and computation), and two intelligent systems (the architect and the architecture machine).’<sup>203</sup> Negroponte’s research group experimented with various scenarios of man-machine interfaces, adaptive and interactive environments, all of which ‘suggested a dynamic and engaged environment in which the co-evolution of the architect and his machines would produce new paradigms of design.’<sup>204</sup>



fig 2.15 Inside the MIT Architecture Machine Group laboratory; around autumn of 1969. The vertical tower rack in the left image is labelled ‘The Architecture Machine.’

In 1975 Nicholas Negroponte published a second book, entitled *Soft Architecture Machines*. A little more than a decade after William Burroughs published his novel *The Soft Machine* in 1961, Claes Oldenburg’s infamous 1962 New York Green Gallery exhibition of *Soft Machine Sculptures* and the Canterbury-based musical outfit *Soft Machine* began its psychedelic journey into the prog-rock fusion, Negroponte prefixed his update to his previous publication with the adjective ‘soft.’ The fashionable prefix hints at understanding architecture as a spatial system capable of correlating with human social activities through the application of technology. Indeed, *Soft Architecture Machines* begins

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<sup>202</sup> Negroponte 1970, x. The ideas contained in *The Architecture Machine* were first set out in the article ‘Towards a Humanism Through Machines’. *Architectural Design*. no. 7/6. September 1969. pp 511-12 and in *Technology Review*. vol 71. no 6. April 1969.

<sup>203</sup> Negroponte 1970, i.

<sup>204</sup> Spyropoulos 2007, 144.

with a retreat from the optimism of *The Architecture Machine* with respect to the hope that computers might take over design activities by application of artificial intelligence.<sup>205</sup> Instead, Negroponte suggests that architectural machines can shape more responsive environments through meaningful interaction with human beings. The soft architecture machines to which the title refers to were of the second type of architecture machine outlined in the previous book.<sup>206</sup> After several years of work the idea voiced in *The Architecture Machine* of replacing the human design with computers was overturned by the conviction that architectural machines ‘won’t help us to design; instead, we will live in them.’<sup>207</sup> As Neil Spiller observes, the kind of architectural machine Negroponte envisioned has still not been fully realized as it involves ‘conversations, self-reflection and empathy, all difficult notions to pin down in the binary world of computer programming.’<sup>208</sup>

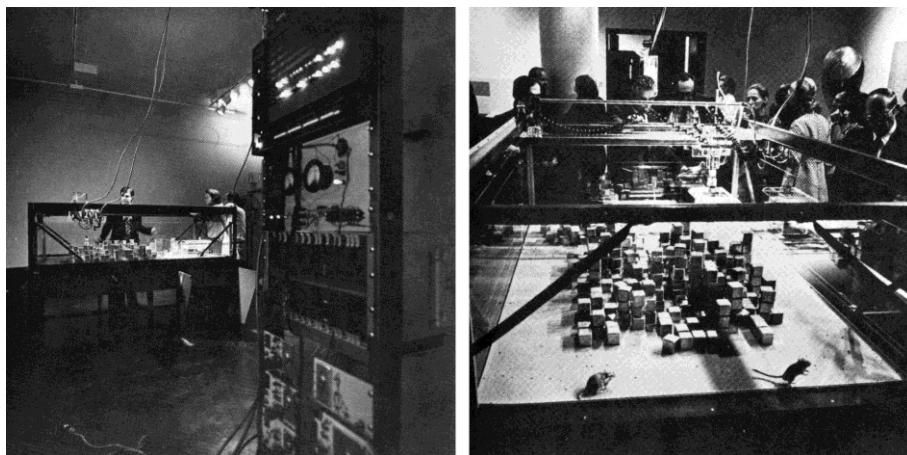


fig 2.16 Architecture Machine Group. *SEEK*. 1970.

The exhibition features an interplay between the machine *SEEK* and a colony of gerbils. The installation was featured at the Jewish Museum in New York in autumn 1970.

Founding notions of how man-machine interactions could also intensify relations to architecture were developed by American physician Warren M. Brodey in his article ‘Soft

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<sup>205</sup> British architect John Frazer, who was instrumental on setting up the computational framework for Price’s *Fun Palace* observes that ‘Negroponte placed high expectations first in computer hardware, then on software through artificial intelligence’ See Frazer 1995, 17 or Frazer in Menges and Ahlquist 2011, 153.

<sup>206</sup> See [http://www.networkarchitecturelab.org/discursions\\_2/soft\\_architecture\\_machines](http://www.networkarchitecturelab.org/discursions_2/soft_architecture_machines), accessed 7/7/2012.

<sup>207</sup> Negroponte 1975, 5.

<sup>208</sup> Spiller 2008, 11.

Architecture: 'The Design of Intelligent Environments' (1967). In criticizing that man has allowed 'hard shell machines to control human beings' Brodey proposes the concept of 'an intelligent environment softened by a gentle control.'<sup>209</sup> He envisions 'creative flexibility' arising from man-made environments that are capable of self-management, self-organisation and predictive, purposeful behaviour. It is in these terms Brodey described his hypothetical environments as 'soft architecture'. Negroponte drew reference to Brodey's article but criticized that it does 'not present convincing examples or give the slightest inkling of a picture or description of how such a system might work.'<sup>210</sup>

After its 'soft' phase Negroponte's Architecture Machine Group would turn its interest towards the integration of the computer into the office workplace, and eventually became what is today known as the MIT Media Lab.<sup>211</sup> In 1976, the group began to work on what Negroponte and his co-researcher Richard Bolt called 'spatial data management.'<sup>212</sup> The idea was 'to turn the computer into a memory palace – or, more precisely (and prosaically), a memory office.'<sup>213</sup> The Architecture Machine Group created what Steward Brand describes in his book on the MIT Lab as 'a room-sized personal computer where the whole body [is] the cursor-director.'<sup>214</sup> In the late 1970s the MIT Media Lab would explore government- (and military-) funded experiments such as *Movie Map* where 'a stranger to a town can sit at a computer terminal and take a detailed journey through the town via films and still photographs which have been stored in the computer,' and the project *Dataland* which 'provides a multi-media environment in which vast and varied databanks can be explored [where] it is possible to focus on a specific area ... for example Boston, and then to get a street map of Boston.'<sup>215</sup> These early experimental harbingers prefigured today's web-based environmental data landscapes, Google map, Bing map etc. – the architecture machine made up of a vast ecology of machines (satellites, servers, cameras, etc.) that ambitiously seeks to reproduce all marine, geological and architectural

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<sup>209</sup> Brodey 1967, 9.

<sup>210</sup> Negroponte 1975, 134.

<sup>211</sup> Negroponte founded the MIT Media Lab in 1985 with support from then MIT president Jerome Weisner.

<sup>212</sup> Brand 1989, 138.

<sup>213</sup> Woolley 1992, 140.

<sup>214</sup> Brand 1989, 139.

<sup>215</sup> See short article 'Alice in Dataland,' *New Scientist*. vol 84. no 1181-88. November 1979. pp 505.

features of the entire world. Negroponte's earlier visions of a softer architecture enriched by a 'humanism through machines' might have given way to corporate and military funded strategies but also shows the potential of fundamental architectural research and experimentation.

## **Interaction with architectural machines**

The visions set out by Negroponte, Price, Pask et al. in the 1960s and 1970s opened up new avenues for the advancement of architectural design through machines. The computer has since then completely revolutionized architectural design practices. Computer-based design strategies such as algorithmic, parametric and digital modelling would profoundly affect the ways architects could interact with their designs.<sup>216</sup> But as Lucy Bullivant observes, architecture risks becoming a screen-based medium in its adherence to imagery, and interest in interactivity is fostering an experimental dissolution of disciplinary boundaries.<sup>217</sup> Interactive architecture, as a more tangible aspect of man-machine relations, began to fully manifest itself in the 1990s when, in contrast to the early beginnings where research activities with computers required government funding, sophisticated computational equipment such as sensors, actuators, wireless networks and computers became technologically and economically feasible to implement.<sup>218</sup> As a consequence, as Fox and Kemp explain in their book *Interactive Architecture* (2009), architecture's longstanding alliance with mechanics began to be re-examined under the premise that architecture could be improved by integration of modalities of adaption,

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<sup>216</sup> See Menges Ahlquist 2011.

<sup>217</sup> See Bullivant 2006, 9. Bullivant's position is similar to Lebbeus Woods' who, in conversation with Hernan Diaz Alonzo, sees architectural representation moving towards strategies that are an embodied alternative to virtuality and non-physicality of digital computing. Woods states: 'My contention was and remains that there will be a resurgence of analogue computers, with which Hernan did not disagree. The digital revolution is over. While refinements in software and hardware will continue, digital computers have won their central role and will not lose it, short of a collapse of the present civilization. However, they have their limitations and these are already becoming clear. The breaking of the world down into infinitely manipulable bits and bytes leaves a vast empty space in human thought that cannot be filled, or should I say 'represented' in that way. Without representation in some form thought cannot exist. This is where analogue representation comes into the story.' See <http://lebbeuswoods.wordpress.com/2012/02/29/the-next-revolution/>, accessed 2012/7/18.

<sup>218</sup> Fox and Kemp 2009, 18.

response and interaction.<sup>219</sup> Indeed, since computing has become integral part of social infrastructures it makes sense that interactivity has become part of architectural thinking as well.<sup>220</sup> In academia, institutions such as *The Interactive Architecture Workshop*, established by Steven Gage in the early 1990s at London's Bartlett School of Architecture, became a pioneering forum and since then numerous architectural schools have expanded their curriculum to incorporate interactive design.<sup>221</sup>

### **Embedded computing and kinetic design**

Programming, kinetic engineering, and robotics are amongst the fields that make interactive architecture a multidisciplinary subject.<sup>222</sup> The crossing of disciplinary boundaries produces complex systems by converging skills, strategies and methodologies. As Lucy Bullivant notes the design and construction of technologically advanced architectural environments 'pursues and applies scientific exploration of many kinds, social, biological, physical and chemical, for quests of a culturally demanding nature rather than strictly rational purposes.'<sup>223</sup> On a technical level, one of the most distinctive aspects of the interactive architecture approach is the structural and operational correlation of machine kinetics (as performing hardware) with the programming of its behaviour through software-hardware interfaces such as Arduino, Make Controllers and software packages such as MaxMSP with MIDI.<sup>224</sup>

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<sup>219</sup> Fox and Kemp 2009, 18.

<sup>220</sup> Bullivant 2006, 119.

<sup>221</sup> See Gage 1998. Some notable programs are the Hyper Body Research Group at the TU Delfts, the Architectural Association Design Research Laboratory and the Centre for IT and Architecture at the Royal Danish Academy of Fine Arts, School of Architecture, amongst others.

<sup>222</sup> Fox and Kemp 2009, 187.

<sup>223</sup> Bullivant 2006, 119.

<sup>224</sup> See <http://www.interactivearchitecture.org/useful-resources>, accessed 13/7/2012.

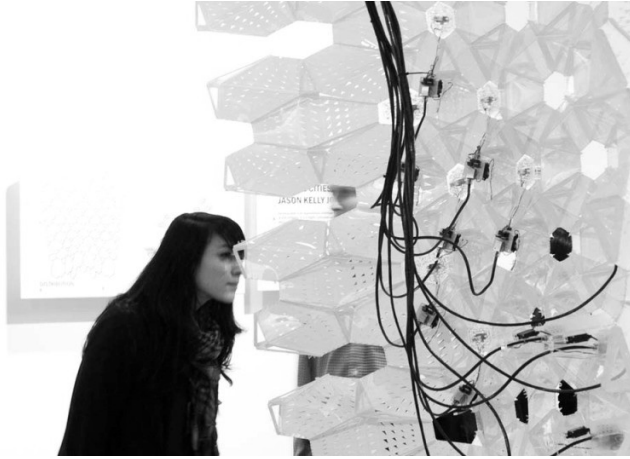


fig 2.17 Future Cities Lab. *Xeromax Envelop{e}s*. 2010.

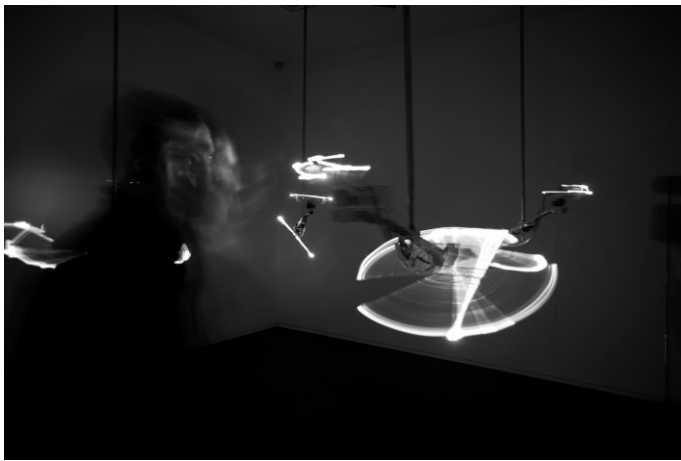


fig 2.18 Ruairi Glynn's *Performative ecologies*. 2007.

Works such Ruairi Glynn's *Performative ecologies* (2007), Omar Khan's *Open Columns* (2007), Philip Beesley's *Organ Reef* (2003) and *Hylozoic Ground* (2010) or Future City Lab's *Xeromax Envelopes* (2010), where virtually all software protocols are specifically programmed, hardware components are custom designed and manufactured, are not only interactive or responsive installations; they testaments of ambitions towards designing machinic behaviour by co-constituent design on a system-level-symbiosis. Interactive architectural machines and installations engage architecture with human capacities and sensitivities in a more tangible, sensual and corporeal manners.

## **Remote Prosthetics**

In a project that stood at the beginning of my engagement with the softening of machines I enquired how machines could overcome their mechanical heritage. The *Remote Prosthetics: Impressions of Transient Proximities* project (2005) endeavoured to think ‘symbiosis’ across systems, asking how the exchange of information, material and form influences the ‘body’ design of machines. The project seeks to infuse architecture’s synthetic space with notions of human corporeality and sensitivity by conceiving machines as corporeal in both their behaviour and appearance. Jasper Chia observes that the project’s ‘[s]oft machines are metaphors to free the machinist and technological bondage from the purely operational. They are proposed as poetical instruments to enable [us] to access conversations with the mythical side of technology.’<sup>225</sup> *Remote Prosthetics* explores how architecture’s space can be extended by turning the soft and sensual logic of the human body onto spatial design.<sup>226</sup> Based on the presupposition that in order to be able to extend the body, technology must become like a body [c4. s1 Like a second sort of body] the system is composed of soft and compliant machines. This relation between prosthetic technology and the body is fundamental to the search for potential symbiotic reciprocities between man and machines that lie at the heart of this project.

The project’s subtitle, *Impressions of Transient Proximities*, indicates that it deals with the temporality of relationships that are constituent to our being in this world. At the conjunction between the worlds of machines and organisms, as well as between the psychic and the technological, *Remote Prosthetics* investigates how human beings engage with non-human, performative artefacts.

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<sup>225</sup> Chia 2005, 32.

<sup>226</sup> Chia 2005; Beuman 2008, 92. Wihart 2009.



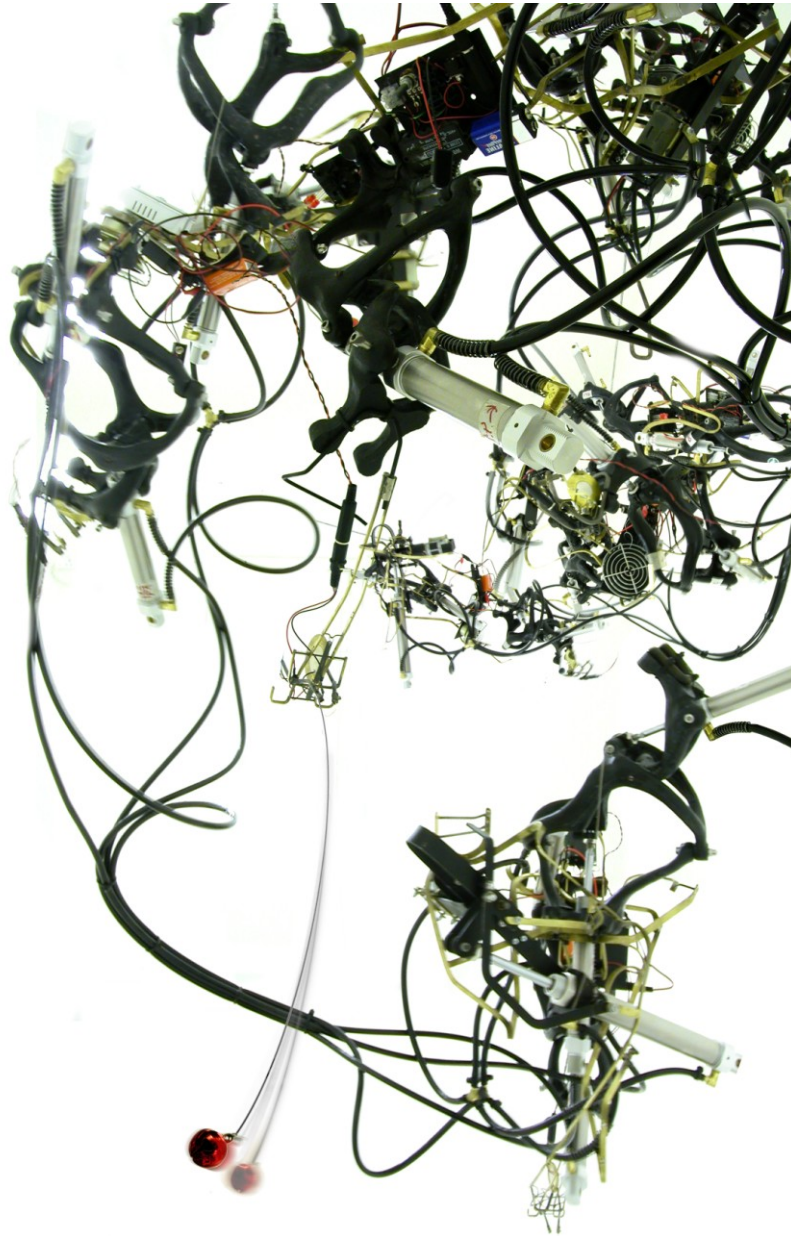


fig 2.19 *Remote Prosthetics: Impressions of Transient Proximities*. 2005.  
Soft machines with Cardanic joints, kinetic hydraulic joints and Hairy microphones,  
custom-designed sensors.<sup>227</sup>

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<sup>227</sup> Wihart in Glynn and Shafiei 2009.

The project's physical nature is complemented by a short text that explores the project's possibilities of exchange in a more imaginary and speculative realm.

Even though soft machines are remote to our body, due to their sensitive capacities and motility, they are intimately linked to our sentiment. *Remote Prosthetics* aspires to notions of intimate and unrestrained man-machine exchanges that are played out on intellectual as well as corporeal levels. Kinetic memories migrate between human bodies in motion and soft machines, which become architectural companions mediating transient conditions of displacement and proximity. The soft machines of *Remote Prosthetics* are connected through a hydraulic network. The exchange of liquids informs their postures. The soft machines not only inquire into the causes of the movement of their own body, but forcibly transfer other soft machine assemblies from their own places, symbiotically and symbolically mimicking gestures of stability and movement.

The chosen methods for induction of movement are derived from concepts of hydraulics and pneumatics. These systems enable flexible transmission of force through tubes, which affords great freedom of positioning and manoeuvring the actuating mechanism in space. The conditions of gravity, friction, elasticity and inertia are integral to this design. The motions of these soft devices are sedate, clumsy and sometimes convulsive. This allows for the induction of spatial movement to be adjusted in spectrums of velocity and force. Through physical experimentation with the mechanics of soft/fluid materials, the dynamics of flexibility and tactile sensing have been designed to suit human interaction. Passive dynamics and compliance have been embedded into the hydraulic system design in order to make the resulting movements soft, slow and indeterminate.

### *Cardanic actuators and Hairy microphones*

The soft machines that constitute *Remote Prosthetics* can stand alone but can also be connected with others. The basic unit of one assembly is a cast GRP (glass reinforced

plastic) cardanic joint with embedded linear actuators.<sup>228</sup> A cardanic joint is activated by pistons in order to alter its position in space. One single joint is operated by two pistons resulting in movement in two independent spatial axes.

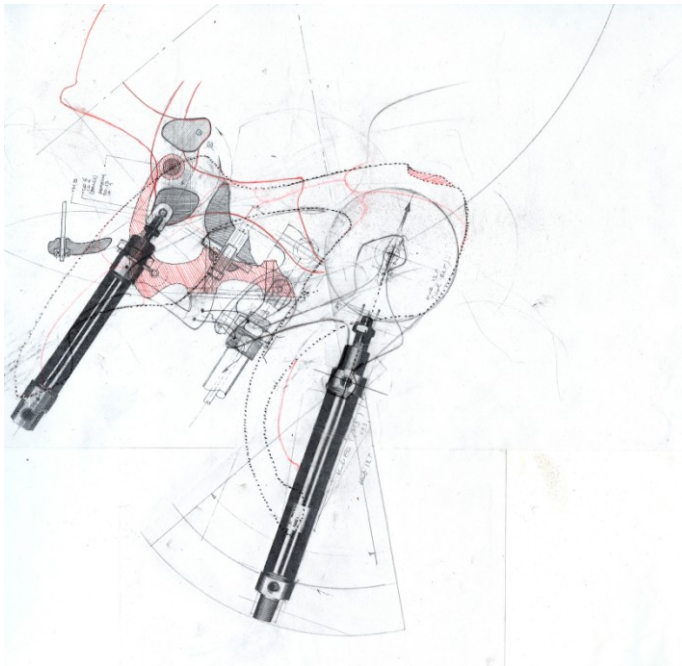


fig 2.20 Cardanic actuator joint. Construction drawing 6.10.

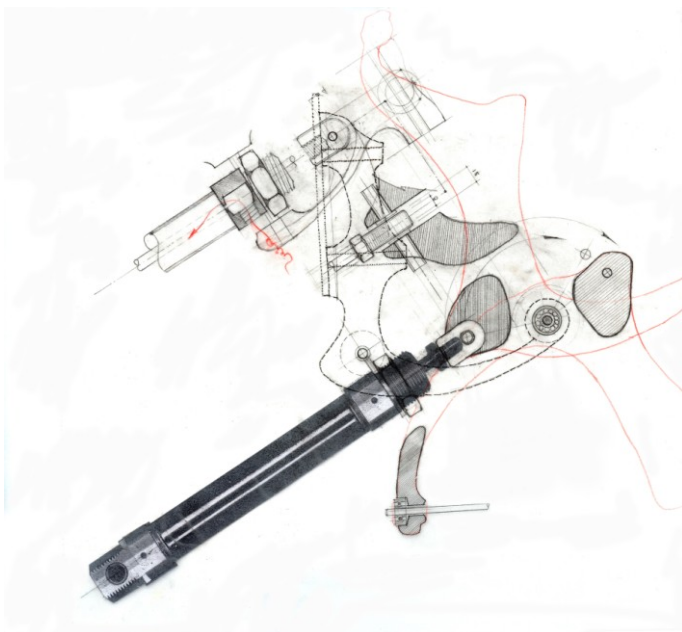


fig 2.21 Cardanic actuator joint. Construction drawing 7.10.

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<sup>228</sup> Wihart 2008, 112; Wihart 2009, 30.



fig 2.22 Cardanic joint.



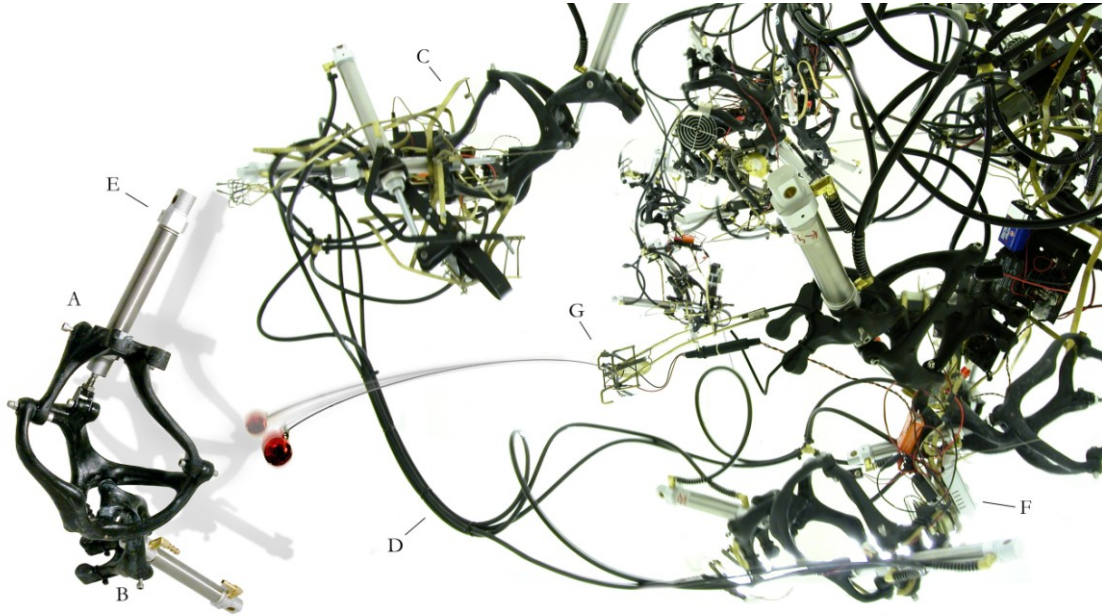


fig 2.23 Soft machines composed of cardanic joints, connected with hydraulic network.

A combination of multiple cardanic joints generates greater spatial occupation. The cardanic joints A B are mounted in a framework C and connected to each other with hydraulic tubes D in such a way that their own weight can reduce or increase the movement initially induced by the pistons E. The tube and piston system is filled with hydraulic oil but a buffer of air remains in each cylinder. Each soft machine has got one piston that is used as a pump. It is controlled by a processing unit F which digitally processes sound that is picked up by a series of sound sensitive devices G, the so-called 'Hairy microphones'.

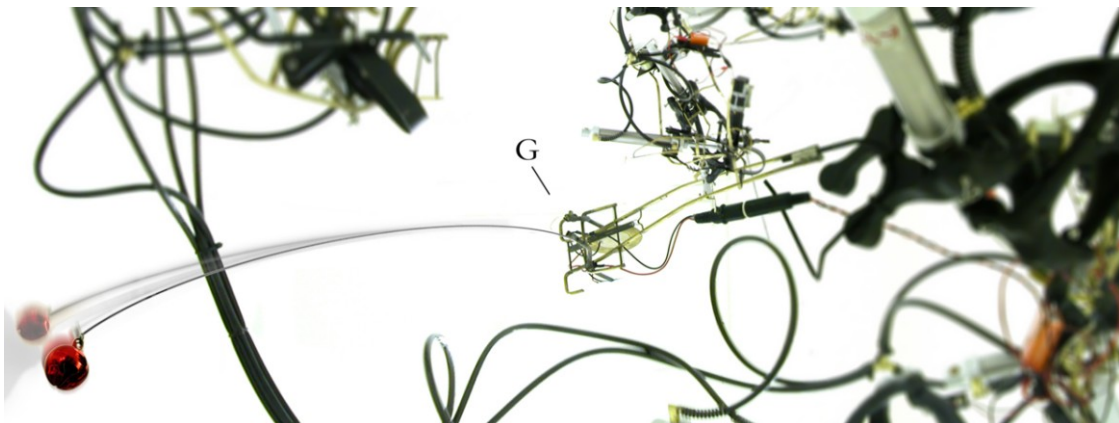


fig 2.24 Hairy Microphones surrounded by soft machines.

Hairy microphones (sensors) (G) are listening to transient impressions of proximities.

As the silicon logic of computers converges with the performative aesthetics of kinetics and custom-designed sensibilities in the body of the architectural machine, the interaction of humans and machines can progress towards more hybrid models that overcome the physical inertness of computers. Indeed, there is a paradox at the heart of the computer, as Neil Spiller observes: ‘it is the least biological-looking of all machines, with few moving parts and operating on invisible electricity, yet it embodies great potential for the hybridization of the animate and the inanimate ...’<sup>229</sup> In this respect, the practice of interactive architectural machine design can be seen as moving towards recreating the behaviour, adaptability and interactivity associated with biological bodies. By convergence with kinetics in the form of architectural machines interactivity allows architectural designers to bring together the world of computation and the world of machine performance. Fox and Kemp put it succinctly when stating that the ‘current landscape of interactive space is built upon the convergence of embedded computation (intelligence) and a physical counterpart (kinetics).’<sup>230</sup> The reconciliation of the previously disjointed condition of software and hardware – a disjunction that essentially goes back to the dichotomy of body and mind introduced by Descartes and reinforced by computer engineering – has created an opportunity to engage with human sensibilities in a more tangible, sensual and corporeal manner. Fox and Kemp have optimistically mapped out these developments by positioning interactive architecture as a ‘transitional phenomenon with respect to a movement from a mechanical paradigm to a biological paradigm.’<sup>231</sup>

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<sup>229</sup> Spiller 2002, 41.

<sup>230</sup> Fox and Kemp 2009, 12.

<sup>231</sup> Fox and Kemp 2009, 20.

### s3 | Biologisation of architectural machines

From allopoietic towards autopoietic machines – Organon-machinae synthesis – Beesley's biophile installations – Bio-inspired design in *Soft Machine dementia*

In 1992 the architectural historian Joseph Rykwert observed that despite architecture's longstanding affirmation of the biological there is

no identifiable organic theory of architecture (based on a direct appeal to nature, at any rate to the nature that biology and chemistry study) that can be usefully summarized. Yet, the constant appeal to the notion of the organism, particularly as it relates to the body image in architecture, seems to be an important recurring theme in speculation about building.<sup>232</sup>

Much earlier Eric Mendelsohn observed that 'the principle of elasticity is dictated by nature. Upon it nature works in all her organisms – in her material, vegetable and animal kingdoms: in man and plant. This is the structural meaning of "organic" architecture.'<sup>233</sup> In contemporary architectural design, mediated by advances in biological, medical sciences and their speculative offsprings, the technology transfer from nature to architecture has become a pervasive strategy.<sup>234</sup> Once belonging to the domain of nature, notions of sensitivity, responsiveness, flexibility, adaptability and autonomy have now been assimilated by architectural machines. It seems as if the softening of machines in architectural design is embedded in the preordained path of the evolution of the technological continuum towards 'living' technologies. But with the emerging interest in 'soft' technologies the question is how organic models are embodied in design and theory of architectural machines.

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<sup>232</sup> Rykwert 1992, 17.

<sup>233</sup> Mendelsohn 1967, 166.

<sup>234</sup> For a detailed account on the development of the 'organic' method in architecture and applied arts, see Steadman, 1978] 2008 and Gruber, Petra. 2011). For the transference of biological models into architectural

## Organon-machinae synthesis

The connotation of the machine with metaphors of living systems signifies developments within the larger technological continuum towards the synthesis of the organic and machinic.<sup>235</sup> This convergence also signals a departure from the congenerous meaning carried by ‘machine’ and ‘organ’ in their etymological origins. When Vitruvius discussed the use and construction of machines in Book X of his *De Architectura* he found it necessary to distinguish between *machinae* and *organa* because the words had such a similar meaning.<sup>236</sup> Joseph Rykwert has pointed out that in antiquity the word ‘organic’ referred to *organon* or *organus* in the sense of instrument.<sup>237</sup> Quite differently, the contemporary slippage of boundaries between machines and organisms signifies the machine’s taking on substitute and prosthetic functions of the organism while reciprocally the organism is becoming entangled with machines – and implies that architecture is transcending its formal relation to the body in favour of operational and behavioural ones. Donna Haraway maintained that ‘[t]here is no fundamental ontological separation in our formal knowledge of machines and organism, of technical and organic.’<sup>238</sup> As Maria Luisa Palumbo points out, from being an ‘instrument of alterity between nature and artifice,’ the machine has become a tool for a ‘dialogue between men, and between man and matter, between man and nature.’<sup>239</sup>

Philosophically, this convergence has been pre-empted by Félix Guattari’s decisive attack on the binary logic and oppositional pairing of the tool and its human operator, the natural and artificial, the organic and the technological, which he formulated in his text ‘Machinic Heterogenesis.’<sup>240</sup> Guattari’s conception of machines is ‘vitalist’, assimilating

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design strategies see Spiller 1998; Spuybroek 2004; Cruz and Pike 2008. For overview of contemporary approaches see Migayrou and Brayer 2013.

<sup>235</sup> Kevin Kelly maintained that despite all technological achievements man sees in organic life the ultimate technology. See Kelly 1994.

<sup>236</sup> See Vitruvius, *De Architectura*, X, 1, iii.

<sup>237</sup> See Rykwert 1992, 340 in Braham and Hale 2007.

<sup>238</sup> Haraway 1991 [1985], 178. The confluence of the machinic and organic has been outlined by Donna Haraway in her seminal *Cyborg Manifesto* where she also states that ‘[l]ate twentieth-century machines have made thoroughly ambiguous the difference between natural and artificial, mind and body, self-developing and externally designed, and other distinctions that apply to organisms and machines (ibid., 152).

<sup>239</sup> Palumbo 2000, 5.

<sup>240</sup> Guattari 1995 [1992]. See commentary on relevance of Guattari’s text for architectural understanding of technology in Braham and Hale 2007, 339.



machines to living beings, in contrast to a ‘mechanist’ conception that ‘empty it of everything that would enable it to avoid a simple construction *partes extra partes*.’<sup>241</sup> Guattari’s heterogeneous machinism, applied to the softer continuum of architectural machine, philosophically reinforces the historical evolution of architectural machines towards more heterogeneous, biologically and socially integrated modalities.

### **From allopoietic towards autopoietic machines**

Luis Fernández-Galiano calls upon the continuous dialogue between the machine and life that manifests itself in the conception of the organism as machine and the machine as organism.<sup>242</sup> With reference to French philosopher Edgar Morin, Fernández-Galiano points out that the machine has gone through progressive steps of approximations to the organism. He describes the approximation of living organisms by artificial machines so far in three stages:

1. mechanics
2. thermal machines (steam engines etc.)
3. cybernetic machines

However, Morin maintained that in order to truly autonomise the notion of the technologically assimilated living being the modelling of living systems must undergo yet another revolution ‘to deliver us from the cybernetic model.’<sup>243</sup> Morin proposed in his extensive critique of cybernetics, *Method: towards a study of humankind.vol 1. The nature of nature* (1992 [1977]) that ‘we must conceive of the machine not as mechanism but as praxis, production, and *poiesis*.’<sup>244</sup> In similar ways, by alluding to Wiener’s ‘cybernetic’ perspective that ‘envisages living systems as particular types of machines equipped with the principle of feedback’ and the ‘systemic’ conception of Chilean biologists Humberto

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<sup>241</sup> Guattari 1995 [1992], 33 [italics in original].

<sup>242</sup> Fernández-Galiano 2000, 151.

<sup>243</sup> Morin 1992 [1977], 248.

<sup>244</sup> Morin 1992 [1977], 163 [italics in original].

R. Maturana and Francisco Varela, Guattari also called for ‘a reconstruction of the machine that goes far beyond the technical machine.’<sup>245</sup>

Conceiving of machines being capable of *poiesis* releases the machine from man-centred purposes in order to imbue it with the self-centred purposes characteristic of natural bodies. In their extrapolation of cybernetic concepts into the biological realm Maturana and Varela position the machine’s generative potential as self-creating unity in relation to the space in which the machine operates. ‘The organization of a machine (or system) does not specify the properties of the components which realize the machine as concrete system, it only specifies the relations which these must generate to constitute the machine or system as unity.’<sup>246</sup> For the machine ‘to constitute a concrete entity in a given space its actual components must be defined in that space, and have the properties which allow them to generate the relation which define it.’<sup>247</sup> In applying the notion of the machine as an explanation model for biological organisms, Maturana and Varela are evoking the technologisation of biology and the reciprocal biologisation of technology. Their concept of the *autopoietic machine* contrasts the productive notion of man-made machines. An autopoietic machine, Maturana and Varela explain,

is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produce them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network.<sup>248</sup>

In contrast to autopoietic machines, *allopoietic machines* ‘produce something other than themselves.’<sup>249</sup> An allopoietic system, such as a car factory for instance, uses raw materials (components) to generate a car (an organized structure) which is something other than

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<sup>245</sup> Guattari 1995 [1992], 34.

<sup>246</sup> Maturana 1980, 80.

<sup>247</sup> Maturana 1980, 80.

<sup>248</sup> Maturana 1980, 78.

<sup>249</sup> Guattari 1995, 39.

itself.<sup>250</sup> Gordon Pask has already observed that other than the machine with a goal, such as a thermostat, machines are always part of an evolving man-made system. 'It is, if you like, a much more biological notion, maybe I am wrong to call such a thing a machine; I gave it that label because I like to realize things in artefacts.'<sup>251</sup>

The idea of an autopoietic machine challenges the notion of deterministic functionality and in parallel with its biological siblings includes its own transformation and destruction. The great potentials and inevitable consequences of granting autonomy and adaptability to machinic creations have been discussed by California-based tech-guru Kevin Kelly in his book *Out of Control: The New Biology of Machines* (1994). As prophet of post-modern technology Kelly suggested that autonomy and adaptability found in the natural world will become a model for the conception of artificial systems. As a consequence, Kelly warns, autonomous machines and systems might take on a life of their own. '[A]s we unleash living forces into our created machines, we lose control of them. They acquire wilderness ...'<sup>252</sup> Kas Oosterhuis extended this notion into architecture. Buildings might become animated and 'wild' as they respond real time to the behaviour of their inhabitants.<sup>253</sup>

### **Beesley's biophile installations<sup>254</sup>**

The implication of developing architectural systems capable of autonomy and adaptability can be discussed by looking at Philip Beesley's 2010 Venice Biennale installation *Hylozoic Ground*.<sup>255</sup> Beesley provocatively observed that his installations 'treat you much like any

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<sup>250</sup> However, as Guattari points out, if allopoietic systems are considered 'in the context of the machinic assemblage they constitute with human beings, they become ipso facto autopoietic' (Guattari 1995, 40).

<sup>251</sup> Quoted in Bateson, Mary Catherine. 1972. *Our Own Metaphor: A Personal Account of a Conference on the Effects of Conscious Purpose and Human Adaption*. New York: Alfred A. Knopf.

<sup>252</sup> Kelly 1994, 4.

<sup>253</sup> See Oosterhuis 2002.

<sup>254</sup> The term 'biophile' suggests an instinctive and archetypical bond between human beings and other living systems. This hypothesis has been popularized by the American biologist and theorist Edward O. Wilson in his book *Biophilia* (1984). Although Wilson did not mention it in this book this concept was introduced in 1964 by the German-American social psychologist and philosopher Erich Fromm in his book *The Heart of Man*, which describes man's instinctive and psychological orientation to all that is alive and vital.

<sup>255</sup> The installation is Canada's entry to the Biennale di Venezia 12<sup>th</sup> International Architecture Exhibition. See publication Beesley 2010 a.

wild animal would treat a human. You are its food.’<sup>256</sup> The predatory nature of the installation is also captured in Terri Peters’ observation, when she notes that ‘once you enter the room you can only hope it is friendly.’<sup>257</sup> Cary Wolfe explains that ‘[p]art of this feeling, no doubt, is not just the experience of being in an enveloping space of extraordinary dimensional depth and texture, but in one that moves peristaltically, at once synchronous and asynchronous with the viewer’s actions.’<sup>258</sup> Without referring specifically to the notion of autopoiesis, Peters added that Beesley’s installations create ‘an environment with no clear beginning or end.’<sup>259</sup>



fig 2.25 Beesley. *Hylozoic Ground*. 2010.

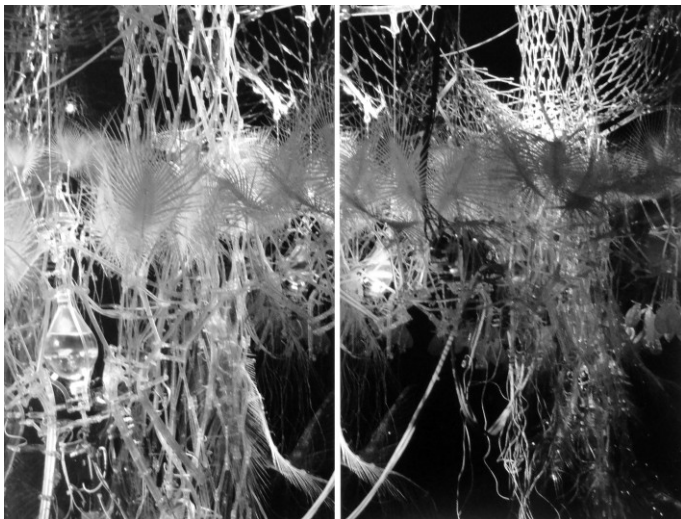


fig 2.26 Detailed internal view of ‘breathing columns,’ ‘filter assembly,’ and ‘protopearl flasks.’

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<sup>256</sup> See McKeough, Tim. ‘This Art Bites’ in *Wired* (November 2007), p 134.

<sup>257</sup> Peters, Terri. ‘Philip Beesley Envisions and Architecture that Breathes and Grows’ in *Mark 21* (August-September 2009), p 201.

<sup>258</sup> Wolfe 2010, 57.

<sup>259</sup> Peters 2009, 201.

### *Bio-technological animism*

As Robert Pepperel observes, the polysemic nature of Beesley's constructions 'variously invoke biological tissue, sculpture, textiles, architectural forms, complex geometries, digital replication, and organic systems ... where the body permeates beyond the membrane of the skin into the space around it.'<sup>260</sup> Beesley himself positions his work at 'a transitional stage between non-living and living substance, constantly forming in nature by a process of disintegration of inorganic and organic matter.'<sup>261</sup> When describing the predecessor of the Venetian *Hylozoic Ground* project, which is a smaller and less complex version, called *Hylozoic Soil* (2007), to American architect Omar Khan, Beesley blurs its technology with metaphorical allusions to anatomical parts of living systems.

Hylozoic Soil ... has the common behaviour of 'breathing' around its occupants. The relationship is, on the surface, gentle. Proximity sensors detect movement, and respond with caressing and swallowing motions. Hundreds of mechanisms—frond-like 'breathing' pores, curling tongues, and groves of twitching whiskers are organized in spiralling rows that curl in and around the mesh surfaces. The whiskers stir the air in thickened areas of the matrix, propelling humidified air and stray organic material over fields of glands and traps. Thousands of primitive glands are clustered through the system, located at the base of each breathing pore and in suspended colonies of whiskers and trapping burrs.<sup>262</sup>

Although Beesley's projects are generally discussed in the context of responsive and kinetic environments they are deeply saturated with Beesley's narrative contemplations on 'humankind's relationship to the land, the interaction of people and earth,' as Michael Stacey observes.<sup>263</sup> In a mythopoetical text [c1. s2 A mythopoetic lesson in architecture] that documents his departure from the Wat Pah Nanachat monastery on the northeast

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<sup>260</sup> Pepperel 2010, 40.

<sup>261</sup> Beesley 2010b, 24.

<sup>262</sup> See Khan, Scholz and Shepard 2009, 27.

<sup>263</sup> Stacey 2010, 59.

border of Thailand in 2004, Beesley recounts his experience during a speech given by the abbot.<sup>264</sup> Beesley is sitting with a smaller group of visitors in a hall cocooned in darkness.

Layers of shadows within the forest canopy cast in bare moonlight far from village electricity ... accompanied by a chorus of cicadas and bulbus ... embroidered dissolving cloak, suffused with starlight and punctuated by miniscule points from fireflies and glow-worms.

Listening and probing the contours of the surrounding forest. Leaf, hanging moss, vine stems trailing through, spun silk web with carapace, disarticulated wing. Moth fluttering below, dried leaf above wet leaf ...

Hard shell of cast cicada skins, viscous soft skin of larvae ... Root tendrils, running through humid mass ... Millipede, arcing amidst hundreds of legs moving in chained peristalsis. A colony of slugs, bodies pulsing in glacially slow swaths.

Beneath the soft bodies of snails, glistening sheen of path excluded: cellulose digested by microbes, aphids and mites, microbes boiling.<sup>265</sup>

These poetic narratives strategically shift the work beyond its non-organic gestation into a realm of bio-technological animism. As R&Sie<sup>(n)</sup> note in the context of their own work – which often deliberately blurs the boundaries between man-made and the grown – that it is not only about ‘taking the impact of biological effects [in architecture] beyond the realm of physiological transfers but to induce a narrative system that evolves a heterotopian relationship with the body.’<sup>266</sup> These transfers are reminiscent of the blurred boundary between machines and living organisms that permeates William S. Burroughs’ fiction (‘liquid typewriters plopping into gelatin’ or viruses attacking the organism reducing it to a ‘paralyzed larva, slobbering and covered by caustic green slime’<sup>267</sup>) [c3. s2 Excuse: William S. Burroughs’ *The Soft Machine*]. Life, it seems, shall no longer remain the exclusive domain of nature. As an ‘alchemic architect,’ as Neil Spiller observes, Beesley is driven by

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<sup>264</sup> This text is part of Beesley’s introduction to his monograph *Kinetic Architectures & Geotextile Installations*. Beesley 2010b, 24.

<sup>265</sup> See Beesley 2010b, 24-25.

<sup>266</sup> R&Sie<sup>(n)</sup> in Cruz and Pike 2008 [Neoplasmatic Design], p 68-69.

<sup>267</sup> Quotes taken from *The Soft Machine* (1961), *The Ticket That Exploded* (1962) and *Nova Express* (1965).

‘a belief in enlivening the vital force within materials; liberating the attributes of the material world ... and then deploying these forces architecturally.’<sup>268</sup>

### *From soil to plastic forests*

Beesley’s work itself has undergone various transitional phases. A brief recapitulation shows how installations turned into responsive environments by introduction of sensitivity and actuation capacities. Beesley’s early installations *Haystack Veil* (1997) *Erratics Net* (1998) were primitive field sculptures installed in a natural environment, while projects with the evocative name *Hungry Soil* (2000) were paradoxically installed inside a building.<sup>269</sup> With *Gill Array* (2002) and *Orgone Reef* (2003) Beesley’s work has become increasingly technologically sophisticated by turning to digital manufacturing. Constructed at the limit of their structural integrity in order to allow them to deform with gravity and respond to the slightest change in wind or air pressure, acrylic glass module assemblies are installed inside a building space.<sup>270</sup>

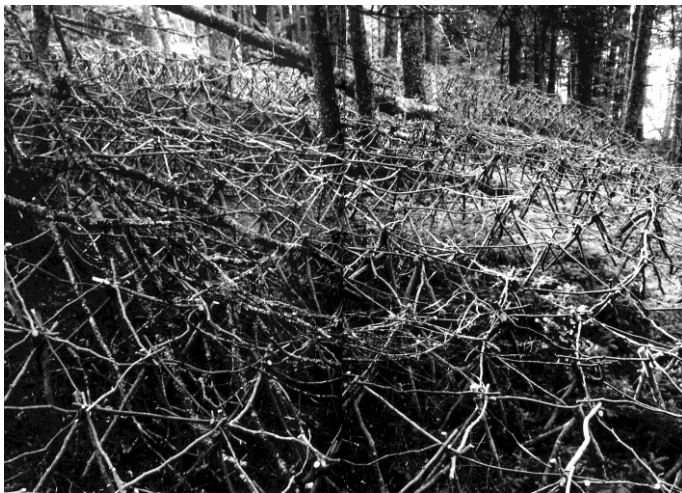


fig 2.27 Beesley. *Haystack Veil*. 1997.

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<sup>268</sup> Spiller in Beesley, 2010 a, p 50.

<sup>269</sup> Installation at Roma XX Exhibition, BCE Place Galleria in Toronto, Ontario in 2000.

<sup>270</sup> Macy 2010, 32.



fig 2.28 Beesley. *Orgone Reef*. 2003.

As Christine Macy observed, in subsequent projects, such as *Orpheus Filter* (2005), *Implant Matrix* (2006) and *Hylozoic Soil* (2007) the fragile acrylic matrix was fitted with mechanical and computational equipment in order to enable the installation to respond to people entering the room.<sup>271</sup> This advance in Beesley's works was a consequence of collaboration with researchers at MIT's Media Lab, after which Beesley began to incorporate microprocessors linked to small actuators (mechanical devices such as pumps and vibrators) into his work, enhancing their lifelike qualities.<sup>272</sup>

### *Incubators, protocells and designed metabolisms*

The collaboration with medically trained architectural researcher Rachel Armstrong extended the kinetically responsive behaviour of the Venice *Hylozoic Ground* (2010) project with 'living' technology that 'embodies some of the properties of living systems.'<sup>273</sup> In modelling a 'synthetic ecology' artificial organs called 'incubator,' and 'protopearl flask' are introduced.<sup>274</sup> According to Armstrong, these organs function like biological organs, housing an aggregation of specially engineered protocells. 'A protocell is a model of a cell that is formed by the innate, complex chemistry of molecules that exist at the interface

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<sup>271</sup> Macy 2010, 32.

<sup>272</sup> Macy 2010, 32.

<sup>273</sup> Armstrong 2010, 127.

<sup>274</sup> Armstrong 2010, 127.



between oil and water.<sup>275</sup> Within the incubators, protocells are generated from an ‘arrangement of water molecules in an oil-based environment that undergo a dynamic interaction with iron and copper based minerals.’<sup>276</sup> Not unlike the infamous incubator of Cornelius Drebbel<sup>277</sup> the incubator alludes to alchemic processes.

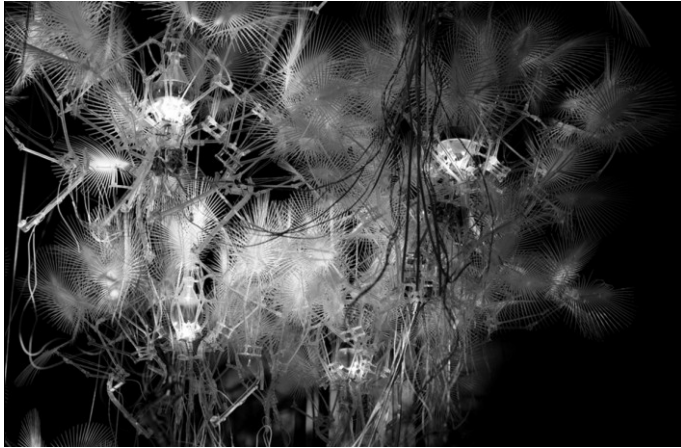


fig 2.29 Philip Beesley and Rachael Armstrong. Protocell flask in Hylozoic Ground field. Canadian Pavillion, Venice Biennale 2010. Incubators and protopearl flasks suspended in filter clusters.



fig 2.30 Detailed view of Protopearl flask.  
Harmless, pearl-like carbonate deposits result from the processing of Venice canal water by protocells

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<sup>275</sup> Armstrong 2010, 128.

<sup>276</sup> Armstrong 2010, 130.

<sup>277</sup> Cornelius Drebbel (1572-1633), a Dutch engineer and inventor, invented a thermostatic furnace that could maintain a constant temperature for the generation of gold from lesser substances, following alchemist's belief that heating materials for a long time would convert them into gold. Otto Mayr maintains that Drebbel's incubator is 'the first feedback system invented since antiquity' (Mayr 1970, 127). The incubator was also admired by a young Christopher Wren, then a student of astronomy who would become the well known architect of London's St Paul's cathedral in his 'second' career (de Moncony diary note after meeting Wren in *Journal des voyages de Monsieur de Monconys*, Volume 2, 1663, pp 42-54).

The interaction of the incubator with the installation is not made entirely clear. But in contrast to the incubator, which is a material system closed to the environment, the protopearl flask ‘exists within an open system of material flow.’<sup>278</sup> The flask contains a ‘designed metabolism’ of protocells that is engineered to produce a variety different carbonates in interaction with water from the Venice canals and metal ions such as barium, magnesium and calcium.<sup>279</sup> Combined with an LED light and corresponding sensors, dynamic qualities of the protocell solution such as growth and self-assembly, and physical properties such as varying permeability, take influence on the behaviour of the installation. The soft plastic kinetic mechanisms are inhabited by artificial organs such as incubators and protopearl flasks. Rather than existing in a purely inorganic state the installation has become a scaffold supporting primordial artificial organs simulating life.

### **Bio-inspired design in *Soft Machine Dementia***

As part of my own research agenda into bio-inspired machine design, the *Soft Machine Dementia* (2004) project explored the potential for machinic autonomy and surprise.<sup>280</sup> The design problem was: How can the performance of a structure be programmed by its physical design? The resulting design brief and impetus for the experiment was to find out if it is possible to construct a machine using the hydraulic swelling of rubber bladders for the induction of non-repeatable motions.

#### *Pulvinus joints*

Observations in plant physiology have revealed the potential of non-mechanical biological movement systems. The leaves of the sensitive plant *Mimosa pudica* retract upon touch. This movement is induced by liquid transfer within a system of cells, activating the pulvinus joints of *Mimosa pudica* through the osmotic movement of water. K<sup>+</sup> and Cl<sup>-</sup> fluxes mediate the leaf movement.<sup>281</sup> This osmotic transfer of water causes the target compartment to gain volume, exerting hydraulic force on the structure of the plant and in

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<sup>278</sup> Armstrong 2010, 132.

<sup>279</sup> Armstrong 2010, 132.

<sup>280</sup> Chia 2005, 32; Wihart 2009, 30.

<sup>281</sup> See Coté 1995, 729-30.

the process bending the leaf. This process is called turgor movement. The leaf-moving organ is called pulvinus.<sup>282</sup>

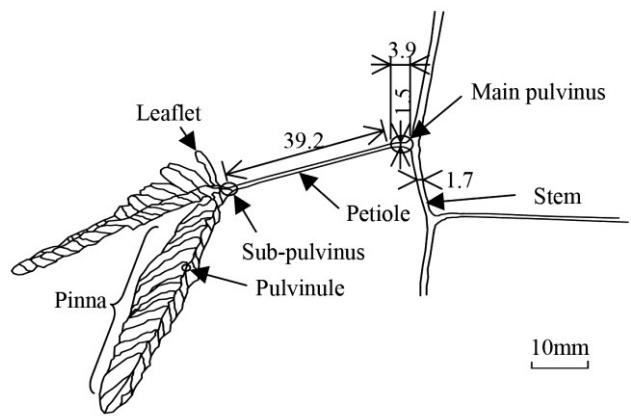


fig 2.31 *Mimosa pudica*.  
Plant stems and leaves, with primary, secondary and tertiary elements.

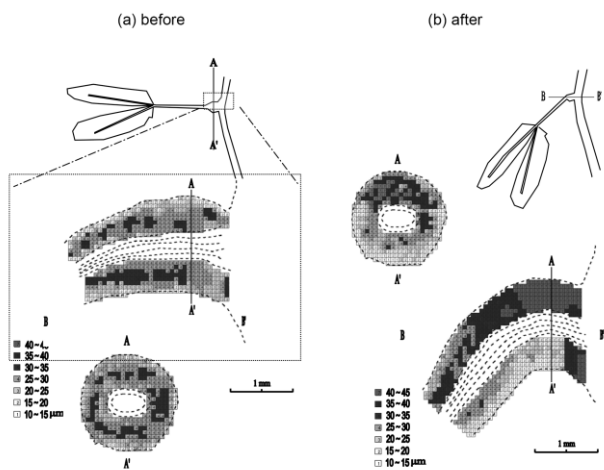


fig 2.32 Pulvinus joint of *Mimosa pudica*.  
Size distribution and Kalium disposal in longitudinal section of main pulvinus joint, before (a) and after (b) stimulation by touch.

A distinctive characteristic of pulvinus joints is that motion is induced within the joint, as opposed to being imposed onto the joint as in musculoskeletal systems.<sup>283</sup> I have recreated this system by constructing a closed system of rubber bladder joints. The bio-inspired

<sup>282</sup> Elastic movement systems such as pulvinus joints are not only found in leaf movement systems but also in seed deployment mechanisms such as in fern sporangia.

<sup>283</sup> Coté 1995, 729-30.

pulvinus joint of the *Soft Machine dementia* are activated by hydraulic pressure, generated by swell gel – a gel that can expand to up to 400 times its volumes by the absorption of water.<sup>284</sup> The mechanical force of swelling is harnessed for the induction of movement.<sup>285</sup>

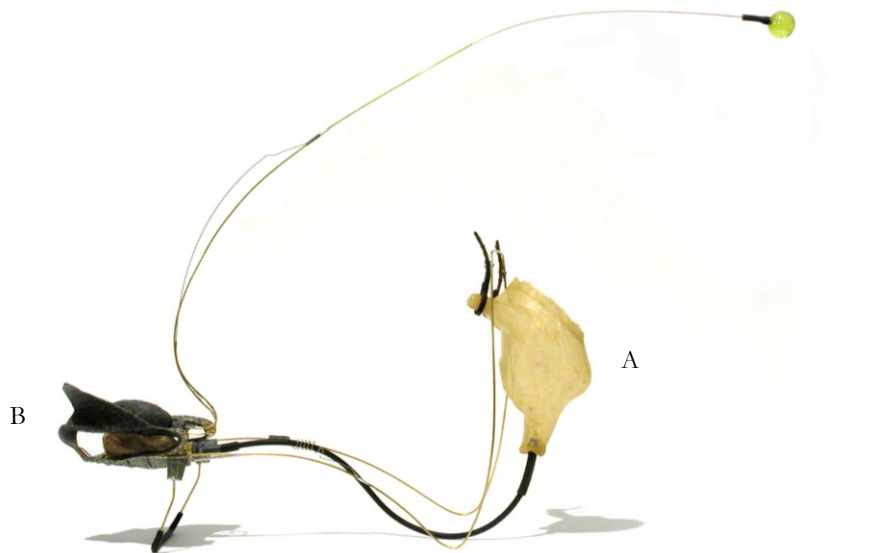


fig 2.33 *Soft machine dementia*. 2004.  
Side view with filled bladder (A) and closed pulvinus joint (B).

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<sup>284</sup> See Appendix 1. The phenomenon was first explored by the late Toyochi Tanaka at the Massachusetts Institute of Technology (Jones 2004, 140). Observations made more than 300 years ago show just how powerful these soft forces can be. In 1676, the pioneering Dutch microscopist Leeuwenhoek described his observations on a tiny, single celled animal connected by a stalk to a fragment of leaf: “...their whole body then leapt towards the globul of the tayl ... and un-wound again. This motion of extension and contraction continued for a while ...”. This contraction of the stalk (spasmoneme) of the vorticellid turns out to be the most powerful organ in biology in proportion to its mass, generating a power per unit mass ten times greater than a car engine. The full details are not yet known. ‘When the stalk needs to contract, the gel is flooded with calcium ions, which neutralise the charge and bring about the collapse of the gel.’ (Jones 2004, 141).

<sup>285</sup> At the time of construction swell gel was the placeholder for a type of transitive gel that could change its shape due to electronic stimulation, which would enable the system to be controlled via Arduino boards of similar computational control devices. Electro Activated Polymers (EAPs) are currently being researched as entirely soft and elastic actuators [c7.s1 EAPs in Elastic actuations].



fig 2.34 *Soft machine dementia*. 2004.  
Side view with empty bladder (A) and swollen pulvinus joint (B).

The *Soft Machine Dementia* uses ‘the gravitational force of water and hydraulic absorption for the induction of non-prescriptive motion.’<sup>286</sup> The device is called soft machine *dementia* because, due to its kinetic configuration it is unable to repeat its performance. Within this soft machine, the bladder A stores water and provides it to pulvinus joint B, which is suspended in the metal wire frame (fig 2.25). When the water is made to flow from storage bladder A to the pulvinus joint bladder B it causes a) movement, as bladder B expands due to the swelling of the gel, and b) the transfer of water from one bladder into the other causes the centre of gravity of the machine to shift from A towards B (fig 2.26). These actions taken together push the long antenna C forward and while sometimes the *Soft Machine dementia* stays upright, sometimes it falls over.

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<sup>286</sup> Wihart 2009, 30.



fig 2.35 *Soft machine dementia*. 2004.

Sequence montage. The soft mechanical design of the machine attempts to create non-repeatable motions.

The *Soft Machine Dementia* project subsequently has led to further research into motion induction with higher degrees of motility. In my project *Raiser from the Ground* (2010) I have studied how combinations of multiple joints with embedded actuation can enable a soft machine to erect, interfold, maintain its balance or seek a specific posture. The project is discussed in chapter 5 in the context of influences and potentials of mechanics of softness in architectural machine design.

## c2 | Conclusion

As insights in biological and life sciences have captured the architectural imagination they have inspired architectural machine designs to move towards ‘softer’ conceptions of technology. The technological synthesis of sensitivity and motility, characteristics normally associated with living bodies, is being attempted by hybrid means of computation and bio-inspired design. Composed of soft kinetic ‘organs’ related to the body of architecture (instead of biological ones) softer architectural machines are gradually aspiring the

confluence of the organic and machinic: a hybridisation that transforms the conception of both. Gilles Deleuze and Claire Parnet have advocated the view that the machine – like the organism – ‘is social in its primary sense, and is primary in relation to the structures it crosses, to the men it makes use of, to the tools it selects, and to the technologies it promotes.’<sup>287</sup> In this respect, what constitutes an architectural machine should not be considered independent from, but rather a consequence of, social, biological and architectural structures. It is not *one* technologically autonomous architectural machine, but the power of its *humanely combined enunciations* that constitutes their heterogeneous nature.

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<sup>287</sup> Deleuze and Parnet 2006, 78.

## PART 2

# **BODIES AND MACHINES FOR SOFTER ARCHITECTURE**





## c3 | The body returns (as soft machine)

Human being-machine symmetries – Technologized bodies – Bodies projected outside themselves

To be a machine, to feel, think, know good from evil ...

Julien Offray de La Mettrie<sup>1</sup>

The human being is not physical by his body. It is physical by its being. Its biological being is a physical system. ... We are physical machines ... this machine-being is itself a moment within a mega-machine that we call society, and an instant within the machine cycle that we call the human race ... We are engaged in an uninterrupted productive praxis, producing our lives, our tools, our villages, our monuments, our myths, our ideas, our dreams ... We are children of the sun ...

Edgar Morin<sup>2</sup>

Am I a man or am I a machine? This anthropological question no longer has an answer. We are thus in some way witness to the end of anthropology, now being conjured away by the most recent machines and technologies.

Jean Baudrillard<sup>3</sup>

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<sup>1</sup> La Mettrie 1747.

<sup>2</sup> Morin 1992 [1977], 380.

<sup>3</sup> Baudrillard 1993 [1990], 57-58.



fig 3.01 Humanoid robots in ‘All is full of love.’ 1999.  
Music video for Icelandic singer Björk, directed by Chris Cunningham.

## Introduction

Friedrich Nietzsche maintained that society can be understood not only in terms of its social and cultural products but also in terms of the particularities of its corporeal practices, ideals and fantasies.<sup>4</sup> Extending Nietzsche’s reasoning Elisabeth Grosz proposes ‘a history of culture that would not simply include or focus on scientific, cultural, economic or military achievements but would explore the self-cultivation of minds and bodies, the human production of itself as a species.’<sup>5</sup> One could extend and extrapolate this meaning to the self-cultivation of minds and bodies through architectural machines. As prerequisites of an architectural understanding of technology – paraphrasing Guattari’s ‘[t]he machine would become the prerequisite for technology’<sup>6</sup> – architectural machines inform ideas of inter-corporeal behaviour, performances and materialities: the spaces between human bodies and machines. The human body-architectural machine relation inevitably reflects back on to ideas of the human body. Developments such as the softening of architectural machines coincide with the integration of human capacities into devices, machines and robots, stipulating the question of how technology penetrates and alters the idea of the human body. The emerging reciprocities between the *humanisation of technology* and the simultaneous *technologization of the human* are consequential for the appreciation of the body as machine inasmuch as machines are appreciated as bodies. Edgar Morin maintained in his magnum opus *La nature* (1977-1992) that the

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<sup>4</sup> Nietzsche 1969 [1899].

<sup>5</sup> Grosz 2006, 188.

<sup>6</sup> Guattari 1995, 33.

technologised human being is reflected in a humanised being of machines.<sup>7</sup> His reflections on the inversion between machines and natural bodies established a concept of the human body, or any natural body, as machine-being that is lived within the social megamachine. Morin argued that the artificial machine can only be placed in this context: it is ‘the last-born of the earthly machine; it is born from the development of the anthropo-social machine.’<sup>8</sup>

Throughout history ideas of the human body have always been challenged by machine developments. The French architect and theorist Georges Teyssot points out in his essay on the prosthetic nature of architecture ‘Hybrid Architecture: An Environment for the Prosthetic Body’ (2005) that the definition and imagination of architecture has been increasingly coloured by extension of our senses by technological means. ‘The historical and continued close connections between architecture and the body, established either analogically or in “reality”, seem irrefutable, from Vitruvianism to seventeenth century mechanism, eighteenth century sensualism, nineteenth century organicism, and to twentieth century “celibate machines” and “dwelling machines.”’<sup>9</sup> Classical accounts of the history of the body in architecture, such as Richard Sennett’s *Flesh and Stone* (1994) explored how notions of bodily attributes such as nakedness, geometry or social restraints have affected the design and conception of architecture and the city.<sup>10</sup> But the classical body is challenged by the new ecologies of media, environments and machines within which humanity exists today. As the notion arises of the human body prostheticized with architectural machines, the notion of a classical, skin-bounded or natural body subsides. In actual fact, the classical and natural body would limit the appraisal of the reciprocity unfolding between bodies and machines. The co-evolution of architectural machines and human bodies within the technological continuum has gradually superimposed new modalities and relations onto our corporeal co-existence with architecture. Man is now conscious of the fact that ‘tools and machines are inseparable from evolving human

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<sup>7</sup> Morin 1977 [1992], 163-165.

<sup>8</sup> Morin 1977 [1992], 166.

<sup>9</sup> Teyssot 2005a, 72.

<sup>10</sup> In his introduction Sennett points out that he began studying the body with Michel Foucault in the late 1970s. Sennett noted that Foucault’s influence may be felt especially in ‘exploring the body in society through the prism of sexuality,’ the liberation of ‘the body from Victorian sexual constraints’ and its consequences, ‘the narrowing of physical sensibility to sexual desire’ in modern culture (1994, 26).

nature.’<sup>11</sup> The capacities of softer architectural machines are reflections of human endeavours to extend the body’s generative capacities and to overcome its limitations.

### *Chapter overview*

A brief recollection of historical conceptions of the human body as machine in section 1 introduces a discussion of William S. Burroughs’ 1961 novel *The Soft Machine*, which forms the conceptual core of this chapter and the intellectual point of departure for the soft machine heterogeneity as a whole. Section 2 then examines various aspects of how ideas of the body have been extended and blurred by co-existence with machines, and the reciprocal relationship between technologized ideas of the body and the ways in which technology aligns, rejects, or affirms human capacities. Section 3 looks at the how body, as societal idea, is both a source as well as a location of technology<sup>12</sup> and examines, along George Teyssot’s prosthetic body hypothesis how ideas of the body can help define and imagine architecture as ‘an environment not just for “natural” bodies, but for bodies projected outside themselves, absent and ecstatic, by means of their technological extended senses.’<sup>13</sup> As corporeal capacities and sensitivities are projected outside the body the promises of humanisation shine onto architecture.

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<sup>11</sup> Mazlish 1993, 233.

<sup>12</sup> Shilling 2005, 176-179.

<sup>13</sup> Teyssot 2005a, 81.

## s1 | Human being-machine symmetries

The mechanical body – Functional Bodies – Soft machine bodies – Excursus: William S. Burroughs' *The Soft Machine* – Architecture for soft machines

The first reference in the natural world for architecture is the human body.<sup>14</sup> However, this connotation should not lead to the idea that the human body is or remains natural. In both the social sciences and humanities the idea of the body that has evolved parallel to the technologization of its environment has turned away from the undisturbed and self-contained entity organized by natural development. The idea of the human body has dramatically changed from its perception as naturally skin-bounded to a manipulable, engineerable entity. Phylogenetically originating from the natural realm but ontogenetically lived within a complex field of technological influences the body has entered new evolutionary trajectories. The body cannot be presumed to be natural anymore, as historian Bruce Mazlish maintains that '[w]e cannot think realistically any longer of the human species without a machine.'<sup>15</sup> Conceiving of the body as a machine inversively has informed perceptions of machines as corporeal.<sup>16</sup> The tight entanglement of the body with technology revises the idea of the body as autonomous biological self in favour of alternative models. The question emerges, as Allucquère Rosanne Stone has asked in her book *The War of Desire and Technology*: 'Where does the edge lie between the person and its prostheses?'<sup>17</sup>

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<sup>14</sup> Even when man-made structures such as buildings and cities have often disengaged man's interaction with nature it is difficult to ignore architecture's 'biological continuum' lived through the human body. See Rykwert 1992, 17.

<sup>15</sup> Mazlish 1993, 6.

<sup>16</sup> Descartes 1664, Burroughs 1961, Morin 1977.

<sup>17</sup> Stone 1995, 37.

## The mechanical body

In William Harvey's *De Motu Cordis* (1628) the human body was depicted as a 'great machine pumping life.'<sup>18</sup> Harvey's discovery that blood was circulated mechanically, challenging the ancient idea that blood was circulated by heat: 'it is by the heart's vigorous beat that the blood is moved, perfected, activated, and protected from injury and decay.'<sup>19</sup> So far, organs such as the brain or the heart have been believed to be 'double organs,' containing both corporeal matter and spiritual essence.<sup>20</sup> Some of Harvey's adversaries, such as René Descartes, even went further and were prepared to believe that the body actually *is* a machine. In his book *Passions of the Soul and The Description of the Human Body* (1664) Descartes suggested that the body works like a machine, that it has the material properties of extension and motion, and that it follows the laws of physics.<sup>21</sup> A century later Julien Offray de La Mettrie published *L'Homme Machine* (1747) in which he extended the Cartesian organism-automaton theory by discussing the problem of the mind as a problem of physics.<sup>22</sup>

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<sup>18</sup> Sennett 1994, 257. Sennett has also pointed out that Harvey's findings about the circulation of blood and respiration led to 'new ideas about public health, and in the eighteenth century Enlightened planners applied these ideas to the city' (ibid., 256).

<sup>19</sup> Harvey 1628, 165.

<sup>20</sup> Sennett 1994, 258. Harvey struggled with his Christian notion of the heart as an organ of compassion, but by the time he published his findings he concluded that the heart was also a machine (ibid.).

<sup>21</sup> *The Description of the Human Body* (La description du corps humain) remained an unfinished treatise written in the 1640s awaiting publication some twenty years later. See Descartes 1664.

<sup>22</sup> La Mettrie 1747 and 1994.



fig 3.02 Jaquet-Droz family. Human automata *The Draughtsman*. around 1770.

The automata use a piece of charcoal to draw four pictures. It was built during the early 1770s by the family Jaquet-Droz, a Swiss clock making family. *The Draughtsman* remains in working condition at the Musée d'art et d'histoire in Neuchâtel, Switzerland.<sup>23</sup>

In describing man as a mortal machine and attributing soul to the mechanical function of matter, the thinking of Descartes and La Mettrie finally disassociated all that was conceived as human, the body-mind duality, from spiritual influences.<sup>24</sup> Descartes and La Mettrie's conceptions of the human body were embedded in a wider intellectual shift from a spiritual to a more analytical conception of the world.<sup>25</sup> As a consequence of this transition the body – inasmuch as the architectural environment itself – became a predictable and measurable organisation principle for human relations. [c1.s1 The mechanisation of architectural thinking].

## Functional Bodies

Architecture's cultural practice has always been influenced by the way its imagination (and representation) of the body changes in relation to technology. One of the more distinctive

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<sup>23</sup> Riskin 2007, 248-249.

<sup>24</sup> The myth goes that Descartes constructed a mechanical woman, named Francine, based on mathematical principles. When discovered on a sea voyage by a fellow passenger, the captain ordered it to be thrown overboard as a product of black magic (in Hultén 1968, 9).

<sup>25</sup> At the end of the sixteenth century Galileo Galilei's (1564-1642) mathematical analysis of free falling bodies described a world that obeyed mechanical laws, and facilitated a mechanical interpretation of the world that gradually and irreversibly began to emancipate not only physical bodies but specifically the human body from a spiritual understanding of the world.



features of modernism was ‘the celebration of the mechanized body.’<sup>26</sup> Le Corbusier’s much-quoted rubric ‘A house is a machine for living in’ [Une maison est une machine à habiter]<sup>27</sup> epitomized an attitude where architecture was affirmed as an ‘environment of the machine aesthetic,’<sup>28</sup> prompting a rethinking of the relationship between technology, architecture and the body. Prophets of the productive and rationalistic meanings of technologization such as Le Corbusier and Buckminster Fuller have projected their enthusiasm for industrial mass production and standardization onto architecture. By that time technophile positions had thoroughly engrossed the human body, as can be shown by a quote by R. Buckminster Fuller, the architect of the ‘dwelling machine’<sup>29</sup> *Dymaxion House* in 1938, where he describes the human body as

a self-balancing, 28-jointed adaptor-based biped; an electro-chemical reduction plant, with segregated stowages of special energy in storage batteries for thousands of hydraulic and pneumatic pumps, with motors attached; 62,000 miles of capillaries, millions of warning-signal, railroad, and conveyor systems; crushers and cranes ... and a universally distributed telephone service needing no service for 70 years if well managed; the whole, extraordinary complex mechanism guided with exquisite precision from a turret in which are located telescopic and microscopic self-registering and recording range finders, a spectroscope, etc., the turret control being closely allied with an air conditioning intake-and-exhaust, a main fuel intake [...] <sup>30</sup>

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<sup>26</sup> Armstrong, Tim 1998, 86.

<sup>27</sup> Le Corbusier 1946 [1923], 100.

<sup>28</sup> Banham noted that the phenomenon of designers and architects trying to ‘fix the correct new style of the Machine age’ was exemplified by Le Corbusier’s fondness for ocean liners, aeroplanes and automobiles (Banham 1984 [1969], 122).

<sup>29</sup> Reference is here made to the Dymaxion Wichita House (1946). ‘Going beyond Le Corbusier’s call for a house that *works* like a machine, Fuller proposed a house that *is* a machine’ [italics in original]. See Hsiao-Yun, Chu and Trujillo, Roberto G. (ed.) *New views on R. Buckminster Fuller*. Stanford, Calif.: Stanford General; London: Eurospan. p 29.

<sup>30</sup> Synnott 1993 and Eastham 2007.

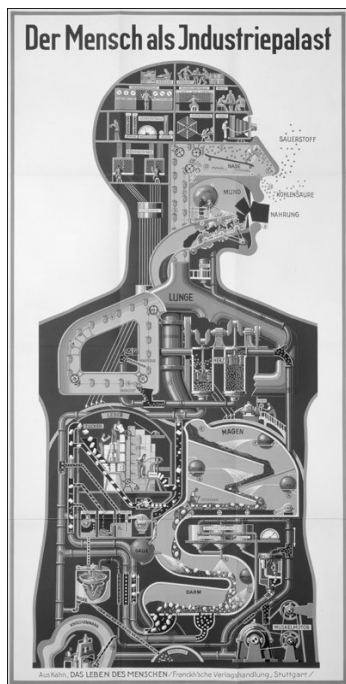


fig 3.03 Fritz Kahn. *Der Mensch als Industriepalast*. 1927.

Kahn's pictorial analogisation of the human body with machines is a pioneering example of information design.

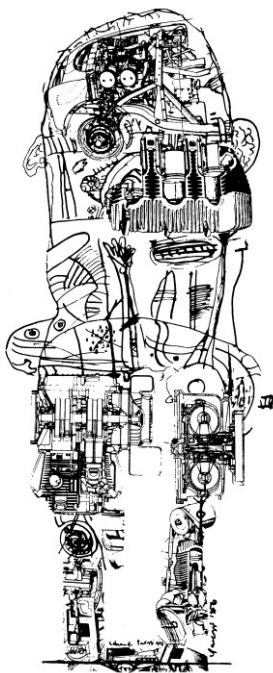


fig 3.04 Eduardo Paolozzi. *Mechanical figure*. 1956.

Paolozzi's drawing was inspired by Kahn's illustrations, as he also embraced technology rather than perceiving it as a demon to be feared. Often cited as an important exponent of Surrealism in Great Britain, Paolozzi's art was driven by his fascination with technology.

Such statements are expression of a functionalist attitude that addresses the biological body as something that can be managed and optimised in cooperation with machines. Eventually, the impact of machines on the design and function of the architectural environment found its historical documentation in Siegfried Giedion's *Mechanization Takes Command: a Contribution to Anonymous History* (1948), a work standing for the mechanical extension of Le Corbusier's dictum 'the house is a machine for living in' or R. Buckminster Fuller's dwelling machines. Similarly to Fuller, the French philosopher Edgar Morin exemplifies the mutual influence of machinic and organic theory, by writing in an almost parodical scientific manner that

the living being is a thermo-hydraulic machine in slow combustion operating between zero and sixty degrees Celsius, eighty percent of which consist of circulating and soaking water; incessantly consuming itself and being consumed ... It is definitely a well-tempered, multi-regulated machine with a formidable informational device.<sup>31</sup>

It is a striking coincidence that while at roughly the same time as Morin portrayed the human body as a 'well-tempered, multi-regulated machine,' Reyner Banham argued for an inclusive consideration of mechanical and electrical services in the history of architecture in *The Architecture of the Well-Tempered Environment*. In lamenting that architects and architectural historians have so far only married architecture and the machine on a metaphorical basis, Banham's methodical analysis of the machine as facilitator of the building's conditioning demonstrates how physiological requirements of the human body can inspire technological responses that in turn inform the design of architecture.

## **Soft machine bodies**

Since Marshall McLuhan proclaimed in 1964 the 'extension of our bodies and senses' the assimilative capacity of technology has occupied not only scientists, economists, sociologists and architects.<sup>32</sup> As always, literature has provided the some of the more speculative fantasies of human capacities extended by technology [s3.s2 Technologized bodies]. The critical capacity of technology to change human self-experience is one of the

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<sup>31</sup> Edgar Morin in Fernández-Galiano 2000, 274.

most distinctive subtexts of the literary creations of William S. Burroughs.<sup>33</sup> In his novel *The Soft Machine*<sup>34</sup> (1961) Burroughs, by his own account, portrayed ‘the human body under siege of technology.’<sup>35</sup>



fig 3.05 William S. Burroughs. *The Soft Machine*. 1961.  
Book cover of first edition.

For a discussion of the relationship between technology and the body, this thesis takes an architectural reading of *The Soft Machine* as an inspirational point of departure. The novel is part of Burroughs‘ famous ‘cut-up trilogy’, including *The Ticket That Exploded* (1962) and *Nova Express* (1965). In this trilogy Burroughs constructed several mechanical, biomechanical or viral prosthetics capable of attaching themselves to or invading the human body. Whether messages are imprinted upon the body by ‘liquid typewriters plopping into gelatin’ or viruses attacking the organism reducing it to a ‘paralyzed larva, slobbering and covered by caustic green slime’ - the abuse of language coincides with radical modifications of the body by the agency of machines.<sup>36</sup>

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<sup>32</sup> McLuhan 1964, 252.

<sup>33</sup> William Seward Burroughs II (1914-1997) was an American novelist, short story writer, essayist and spoken word performer associated with the Beat generation, amongst other writers and poets such as Jack Kerouac (*On the Road*, 1957) and Allen Ginsberg (*Howl*, 1956). Themes Burroughs explored include addiction, the manipulation of the individual by media and government, and more generally existentialism and nonconformity.

<sup>34</sup> The original version of *The Soft Machine* was first published two years after his groundbreaking *Naked Lunch* (published 1959).

<sup>35</sup> Burroughs 1968, 170.

<sup>36</sup> These quotes have been taken from *The Soft Machine* (New York: Grove Press, 1969; Paris, 1961), *The Ticket That Exploded* (New York: Grove Press, 1967; Paris, 1962) and *Nova Express* (New York: Grove Press,

What Burroughs presupposes in these narratives is the ability of technology to fuse, to invade, to alliance with the human body. In short, Burroughs assumes that in order to be able to invade/ extend the body, technology must become *like* the body. Such an assumption echoes George Teyssot's invocation that a critical momentum of technological evolution is its capacity to assimilate the tool with the body. Human artefacts become like a second body when they extend and incorporate our corporeal powers.<sup>37</sup> As Italian philosopher Mario Perniola observes in his book *Sex Appeal of the Inorganic* (2004) that with the emergence of autonomous machines and robots the one-time opposition between inanimate things and humans has been transformed. In order to be able to reframe our understanding of personal experience in coexistence with artefacts that embody sameness, or more seamless interactions, 'we must become a thing who feels, think ourselves closer to the inorganic world and move further from our bodies.'<sup>38</sup> According to Burroughs' radical assimilation of the human body by technology, the qualities of the body are projected into the extracorporeal realm, most notably onto products of technology, such as prosthetics, mutated organisms and biomechanical devices. The projection of attributes is a much-used literary tool in Burroughs' work. In his essay 'A Terminal Case: William Burroughs and the Logic of Addiction' (2002) Timothy Melley points out the parallels between the logic of addiction and the anxieties characteristic of Burroughs' texts. According to Melley one specific feature of Burroughs' writing is the fragmentation of the self into independent entities. Comparing Burroughs' soft machine conceptions to Deleuze and Guattari's 'schizophrenic desiring machines,' Melley points out that this strategy results in the population of the fictional world 'with entities that once constituted the self but are now autonomous.'<sup>39</sup> In other words, Burroughs assigns e.g. 'parasites' with specific behaviour, and they are just that and nothing else. For instance, in Burroughs' 'cellular equation', each cell of the body is imagined as an addict (or non-addict), capable of 'cellular decision' (*Junk*, 151) or 'cellular panic' (*Naked Lunch*, 57). 'What might once have been called the addict's attributes –

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1965). The novels were derived from a six or seven hundred page manuscript that Burroughs compiled over the years. See 'An Interview with William S. Burroughs' (April 4, 1980, New York City), with Jennie Skerl, in *Modern Language Studies*, vol. 12, no. 3, Summer 1982.

<sup>37</sup> Teyssot 2005a, 81.

<sup>38</sup> Perniola 2004, sleeve notes.

<sup>39</sup> Melley 2002, 50.

qualities like decision-making and emotion (panic) – have been transferred to his or her component parts.’<sup>40</sup>

### **Excursus: William S. Burroughs’ *The Soft Machine***

This excursus contextualises the arguments of assimilative exchange between human body and technology established in ‘Soft machine bodies’ with a discussion of Burroughs’ biography and a more specific analysis of machines in the novel *The Soft Machine*. Most studies of Burroughs’ early work centre around the assumption that they are semi-autobiographical meditations on addiction, homosexuality, corruption of the individual by mass media and ‘agents of technology’ and the subsequent loss of control.<sup>41</sup>

Emanating from Burroughs’ work is the concept that the body is the source and location of fiction because it is the location upon which drugs, machines and biological mutations are deployed. When for Burroughs language, as most intimate part of his self, exists only ‘in the infinitesimally small gap-spark between word and thought,’ the field of attack, in order to break language as system, must be the synaptic logic of the brain.<sup>42</sup> Herein lies the extremism of Burroughs’ literary method. According to David Porush, in Burroughs’ ‘apocalyptic mythology, the soft machine is the pure end-product of control by some malicious and all-powerful conspiracy of government, media, and what Burroughs calls the “Nova Police”, agents of technology.’<sup>43</sup>

Because ‘Burroughs nowhere mentions the term’ in the first edition readers are left to their own speculative devices to define what the soft machine actually is.<sup>44</sup> However, Burroughs added an ‘Appendix to the Soft Machine’ to the British 1968 edition,<sup>45</sup> in the first sentence of which we find an explicit definition of the soft machine in his world: ‘the soft machine is the human body under constant siege from a vast hungry host of

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<sup>40</sup> Melley 2002, 50.

<sup>41</sup> Grauerholz 1999, Melley 2002, Porush 1985.

<sup>42</sup> Porush 1985, 101.

<sup>43</sup> Porush 1985, 99.

<sup>44</sup> Porush 1985, 101.

<sup>45</sup> The 1968 British edition has been extensively reworked by Burroughs to give a more traditional structure plus the addition of new material. The appendix was included in no other edition.

parasites.’<sup>46</sup> In the context of Burroughs’ own drug consumption, the vast and hungry parasites are likely to allude to the chemicals attacking the synaptic logic of the brain. In the context of the novel itself the author / protagonist’s paranoia, as Porush has observed, is expressed in the belief that the government and media use agents of technology for the control of people’s minds. The manipulability of that which is human is expressed in the oxymoronic wordplay *soft machine*. *Soft* stands for human, and *machine* for everything against it. The paradox produced by these seemingly antagonistic meanings cannot be resolved. But it can be a leitmotif for a narrative.

### *The Soft Machine and other machines*

Despite his notoriously drug-fuelled lifestyle as a writer, Burroughs’ decadence holds vital clues as to his own attitude towards technology in general and machines in particular. ‘William Seward Burroughs was born in St. Louis, a descendant of the family made rich and famous by the manufacture of calculating machines.’<sup>47</sup> Burroughs, aware from an early age of the machine taking over functions of the human mind by dint of his family’s business with calculating machines, certainly had a specific view on the invasive nature of machines and their potential to change the human condition. If the machine stood for an ideal of perfect functionality in Burroughs’ family history (the calculating machines) then the manipulation of literature by means of his drugged mind would be equivalent to the drugging of the extracorporeal machine.

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<sup>46</sup> Burroughs 1968, 170.

<sup>47</sup> Burroughs’ paternal grandfather invented the adding machine and established the company that bears the family name. See Burroughs’ obituary by George Gessert in *Leonardo*, vol. 31, no. 3, pp. 238-241, 1998, p.238.

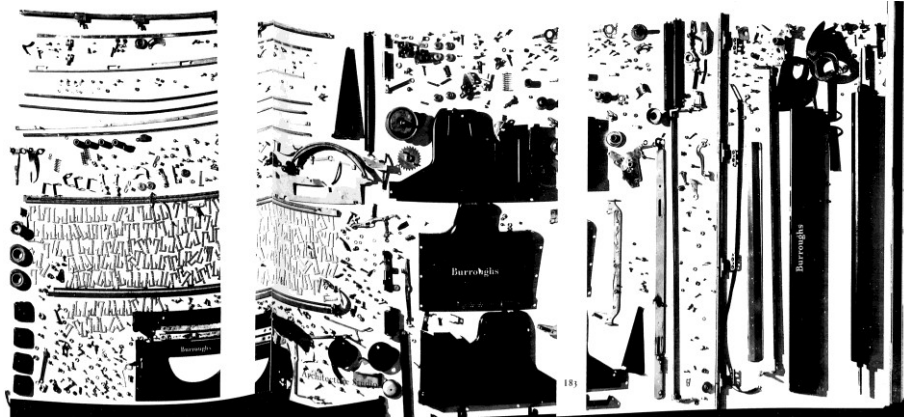


fig 3.06 Jonathan Rader. *1935 Burroughs Typewriter*. 1990.

Original typewriter and individual component parts of disassembled 1935 Burroughs Typewriter.

In Burroughs' novels the conditioning of humans by machines is a dominant theme. In a wider network of political and technological assimilation machines are designed to limit or extend the human body's potential through techniques and equipment that seem harmless or unavoidable. One such machine is a thought control machine. It is encountered in *The Soft Machine* by journalist Joe Brundige, who, on his investigative mission for the newspaper *The Evening News*, travels back in time to Mayan Yucatan by means of a drug cocktail of mushrooms and herbs.<sup>48</sup> Located in a temple, the Mayan thought control machine has been designed by priests to control their workers. The machine's function depends on 'the calendar and the codices which contain symbols representing all states of thought and feeling possible to human animals.'<sup>49</sup> Another narrative is explained in fairly straightforward manner in chapter VII, *The Mayan Caper*. It is a time machine created from newspapers. Burroughs' description of applying this technique is testament to his wild imagination. 'I started my trip in the morgue with old newspapers, folding in today with yesterday and typing out composites...I am literally moving back to the time when I read yesterday's paper, that is traveling [sic] in time back to yesterday...'<sup>50</sup> In a very explicit autobiographic moment Burroughs describes the cut-up technique he used to create the narrative. This technique is called the *cut-up and fold-in technique* and is used to create a non-linear authoring/ reading experience.<sup>51</sup> As an extension of the cut-up method Burroughs

<sup>48</sup> Burroughs 1968, 72.

<sup>49</sup> Burroughs 1968, 73.

<sup>50</sup> Burroughs 1968, 65.

<sup>51</sup> As literary technique it was developed by the Dadaist movement and found further use in the Oulipo movement later in the 20<sup>th</sup> century. Burroughs 'was mixing older writing, cutting up everything from the



later experimented with speech scramblers – the cut-up technique used with electronic tapes and radios.<sup>52</sup> As Burroughs explains in his book *Electronic Revolution* (1971) he envisages the use of scrambled tapes ‘to impose thought control on a mass scale.’<sup>53</sup> Scrambled messages played on tape recorders or the radio could induce a variety of symptoms ranging from forced defecation, laughing, sneezing, hiccuph to spontaneous orgasms.<sup>54</sup> ‘We organise a sex-tape festival. 100,000 people bring their scrambled sex-tapes ... Now a thing like that could be messy, but those who survive it recover from the madness.’<sup>55</sup> The technological manipulation of the human body, invasively or through external stimulation, holds the promise for a symbiotic reciprocity between humans and machines.

[End of Excursus]

## Architecture for soft machines

Burroughs promotes the liberation of the mind from the restraints of control, discipline and rationality. Where the *hard* machine functions efficiently by means of control, Burroughs’ *soft* machine functions by being out of control.<sup>56</sup> Burroughs’ machine is interfaced with technology and chemistry - it is the human body *as* the threshold on which

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past to write an as-yet-unimagined future.’ (Grauerholz and Silverberg 1999, 179). At that time living in Paris with writer and painter Brion Gysin, Burroughs explored the ‘cut-up’ method of composition and the emergence of a ‘Third Mind’ through collaboration. The result was the ‘cut-up trilogy’: *The Soft Machine* (New York: Grove Press, 1969; Paris, 1961), *The Ticket That Exploded* (New York: Grove Press, 1967; Paris, 1962) and *Nova Express* (New York: Grove Press, 1965). For more details on the context of Burroughs’ writing see Waldman 1996.

<sup>52</sup> Burroughs points out that he experimented with cutting up and rearranging – scrambling – his own voice in 1968. He also refers to an article in *New Scientist* June 4, 1970, page 470, entitled ‘Electronic Arts of Non-communication’ by Richard C. French which gives technical instructions and explains that the scrambling technique has been in existence since 1881. See Burroughs 1971, 9.

<sup>53</sup> Burroughs 1971, 10.

<sup>54</sup> Burroughs 1971, 15.

<sup>55</sup> Burroughs 1971, 19.

<sup>56</sup> Timothy Melley points out that Burroughs’ continuous attack on liberal humanism positions the human being as “soft machines”, addict subjects “lived by” a world of technologies that have themselves appropriated the qualities of rationality, integrity, and self-control supposedly lost to human beings’ (2002, 60). Burroughs’ dramatic gesture inverts the relation of human beings with machines and thus creates the technological paranoia for which his work is renowned: machines are human while human beings are machines.

hallucinogenic drugs and machines exchange their capacities. Such augmentation of machines might only be possible in the arts and literature, but they bear fertile thoughts for taking further not only the capabilities of architectural machines but also those of the human body that occupies technologized architectures. The reciprocal relations between the technology of machines and bodies have become one of the most pertinent, yet often sublime, themes in 20<sup>th</sup> century literature concerning architecture's attitude towards technology as a whole. Burroughs' literature offers a radical perspective on the human body under the influence of technological production. However fantastic, dystopian and mind-bending his narratives might be, they highlight coercively causal relations. Very explicitly, the body is positioned as a location of technology. Thus, the imagination of the human body as a naturally evolving / developing given has been compromised. Baudrillard posits a volatile and invasive notion of technology akin to William S. Burroughs' notion of the soft machine human body invaded by technology. Baudrillard analyses: 'The prostheses of the industrial era were all external, *exotechnical*, whereas those we know now are ramified and internalized – *esotechnical*. Ours is the age of soft technologies, the age of genetic and mental software.'<sup>57</sup> In order to invade the body, technology has become *like* the body: an insight that is helpful to every architect who seeks to understand the reciprocal dependencies of human beings and architecture (and the machines that populate and manipulate both of them).

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<sup>57</sup> Baudrillard 1993, 119 [italics in original].

## s2 | Technologized bodies

The engineered body machine – Bodies changed to different forms – Organic bodies blurred (by machines)

The classical tradition took the human body as proportioning and scaling mechanism, from Vitruvius' *De Architectura*, Book III (Section: On Symmetry: in Temples and in the Human Body) to Le Corbusier's *Modulor*. But the blurred boundaries between human beings and machines are what dominate contemporary imagination.<sup>58</sup> Activities such as habitually logging into the Internet, speaking into mobile phones and with computers, mingle 'our humanity with not-so-mute, active, performative objects in a way which we find equally fascinating as disconcerting.'<sup>59</sup>



fig 3.07 Hussein Chalayan. *Animatronic Dresses*. 2007.

The human body extended with technologized fashion. Emerging from collaboration between robotics and interaction, designer Moritz Waldemeyer, fashion designer Hussein Chalayan and the studio 2D3D the dress is driven by a complex set of micromotors with tiny pulleys and nearly invisible cables.<sup>60</sup>

Chris Salter maintains that '[i]t is by now a cliché to say that our traditional understanding of the body is blurred and extended through technical apparatuses.'<sup>61</sup> In the light of these

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<sup>58</sup> Bell and Kennedy 2007.

<sup>59</sup> Pels et al., 2002, 1.

developments, sociologist Margaret Lock and anthropologist Judith Farquhar, in their book *Beyond the Body Proper: Reading the Anthropology of Material Life*, propose an updated anthropology of the body that overcomes the classic problematic ‘body’, which they argue has so far been treated as ‘skin-bounded, rights-bearing, communicating, experience-collecting, biomechanical entity.’<sup>62</sup>

What has emerged from recent scholarship in social sciences has lead to learning to perceive the body as site of ‘more dynamic, intersubjective, and plural human experiences of carnality.’<sup>63</sup> In the context of architectural design Marcos Cruz maintains that recent developments, from critical historicism, high tech deconstructivism to more recent parametric-led biomorphism have failed to appreciate the generative and co-constituting potential of the human body. In his book *The Inhabitable Flesh of Architecture* (2014) Cruz urges to critically asses the ‘cyborgian body aesthetic’ in contemporary architecture.<sup>64</sup>

How then is human corporeality and sensuality transformed when it is technologized by architecture, imaged and imagined through machines, its sensitivity and motility challenged by robots and aesthetics contested by the transformation of its flesh? How does the technologization of the human body change its imagination in architecture? Such questions are urgent as architecture is only starting to develop its own view of the technologized body.<sup>65</sup>

## The engineered body machine

Along this line of thought sociologist Leopoldina Fortunati shows how the body, a natural machine, attracts and envelops artificial machines. The body is machined at a *diagnostic* level (e.g. probes), a *therapeutic* level (pacemakers, radiation therapies), and other technological levels: from *reproductive* ones (in vitro fertilisation), to those of *identity* (plastic surgery, genetic engineering, sex change), to *communicative* ones (mobile, laptop).<sup>66</sup> In fact,

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<sup>60</sup> <http://www.talk2myshirt.com/blog/archives/245>, accessed 30/12/2012; also Seymour 2008, 30.

<sup>61</sup> Salter 2010, 221.

<sup>62</sup> Lock and Farquhar 2007, 2.

<sup>63</sup> Lock and Farquhar 2007, 2.

<sup>64</sup> Cruz 2014, 23.

<sup>65</sup> For discussions of the contemporary body in architecture see for instance Grosz 2001, Armstrong, Rachel 1998;2001.

<sup>66</sup> Fortunati 2003, 76-77.

as architectural researcher and medical doctor Rachel Armstrong explains, contemporary clinical conceptions in scientific disciplines propose ‘a model that, like a machine, can be understood in terms of its mechanics [and] despite the fact that over 98% of our body is fluid, these contemporary models essentially treat the body in the same manner as mechanical systems ...’<sup>67</sup> The current mechanical model of the working human body is based on biomechanical principles. ‘The body machine is thought of as being a hugely complex system of interacting proteins, metabolites and minerals.’<sup>68</sup> The body as fluid, or soft machine - ‘the technologized body ... is more easily linked to, and able to interface with, its environment.’<sup>69</sup>

### **Bodies changed to different forms**

Ovid, when opening his *Metamorphoses* with the line ‘My intention is to tell of bodies changed to different forms’ attributes the mythical power to transform the human body to the gods.<sup>70</sup> Gods are shape-shifting, humans are changed into trees or animals: Daphne turns into a Laurel tree; Arachne is turned into a spider. Two thousand years later, the narrative of ‘bodies changed to different forms’ evokes the power of technology. As Marie O’Mahony, curator of the exhibition ‘The Soft Machine – Design in the Cyborg Age’ at the Stedelijk Museum of Modern Art in Amsterdam (1998-99) suggested, the cyborg, enhanced by mechanical, electronic or chemical means, seems within reach.<sup>71</sup> Plastic surgery, prosthetic implants, immersive computing, bio-technological engineering, fetishism and weight-loss hysteria, are feeding contemporary mythologies of corporeal transformation. In parallel to medical developments, such as cochlear implants or retinal implants, prosthetic mythologies are expanded foremost and radically in literary genres such as cyberpunk, the performative arts, and Japanese Anime.

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<sup>67</sup> Armstrong 2001, 240.

<sup>68</sup> Armstrong 2001, 241.

<sup>69</sup> Armstrong 2001, 240.

<sup>70</sup> Ovid, *Metamorphoses*, transl. Rolfe Humphries (Bloomington: Indiana University Press, 1955), Book I, p. 3.

<sup>71</sup> O’Mahoney 2002.



fig 3.08 *Ghost in the Shell 2: Innocence*. 2004.

The sequel to the 1995 film, *Ghost in the Shell* is based on the manga by Shirow Masamune. The film was written and directed by Ghost in the Shell director Mamoru Oshii. The story is set in the year 2032 and proceeds on the assumption that by this date ‘cybertechnology will have pervasively infiltrated human society irrespectively of any cultural or political boundaries, and that traditional lines of demarcation between the organic and the artificial, the human and the machine, the self and the other will have become downright redundant.’<sup>72</sup> ‘Humans have forgotten that they are human, and the few who still own an organic body coexist with cyborgs (human spirits inhabiting entirely mechanized bodies) and dolls (robots with no human elements at all).’<sup>73</sup>

In the 1980s influential figures such as performance artist Stelarc, cyberpunk writer William Gibson<sup>74</sup> and *Ghost in the Shell*<sup>75</sup> author Shirow Masamune fuelled fantasies of the prostheticized human body, cyborgs, androids, software identities, the wired and / or drugged brain and borderline human consciousness suspended between machines, the

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<sup>72</sup> Cavallaro, Dani. 2007. *Anime Intersections: Tradition and Innovation in Theme and Technique*. Jefferson, North Carolina: McFarland and Company. p 103.

<sup>73</sup> Text is taken from film production company Production I.G webpage, [http://www.production-ig.com/contents/works\\_sp/01\\_/index.html](http://www.production-ig.com/contents/works_sp/01_/index.html), accessed 5<sup>th</sup> November 2011.

<sup>74</sup> William Gibson’s debut novel *Neuromancer* (1984) is considered a seminal novel in the cyberpunk genre and beyond. Gibson’s novels generally deal with cyborgian identities, machine-human symbiotics embedded and governed by post-industrial corporate power. In *Neuromancer*, Gibson coined the term ‘cyberspace,’ describing it as ‘consensual hallucination experienced daily by billions of legitimate users’ (1985, 67). The infamous vilification of the human body as meat puppet also debuted in *Neuromancer*. Larry McCaffery observes that ‘the meat puppet image in *Neuromancer* seems like the perfect metaphor for how the soft machine of our living bodies is manipulated by outside forces’ (1991, 267). For a discussion of technology and the body in Gibson’s work see David Tomas, ‘The Technophilic Body: on Technicity in William Gibson’s *Cyborg Culture*’, in Bell and Kennedy 2007. pp 175-189.

<sup>75</sup> Shirow Masamune’s *Ghost in the Shell* manga was first published in 1989 in *Young Magazine*. Based on the manga, the Japanese animated science fiction film was directed by Mamoru Oshii and released in 1995. The sequel *Ghost in the Shell 2: Innocence*, was released in 2004.

virtual and the real. Mainstream cinema has adapted these narratives: *Blade Runner*<sup>76</sup>, *Terminator*,<sup>77</sup> *Dark City*<sup>78</sup>, *The Matrix*<sup>79</sup> and *eXistenZ*<sup>80</sup> are telling contemporary versions of Ovidian tales of corporeal transformation.

### **Organic bodies blurred (by machines)**

In their analysis of contemporary cultures of technological embodiment sociologists Mike Featherstone and Roger Burrows point out that '[t]he key analytical categories we long have used to structure our world, which derive from the fundamental division between technology and nature, are in danger of dissolving.'<sup>81</sup> Featherstone and Burrows argue that the hybridization of humans with computers and machines generates a powerful metaphor for a new sociology of technology. In this regard, sociologist Chris Shilling distinguishes two interrelated developments that have significantly contributed to the 'rise of technologized bodies in the contemporary era.'<sup>82</sup> The first is the proliferation of *cyberspace*, the virtual space created by computer mediated communication 'in which people can interact or access information without having to be co-present with others.'<sup>83</sup> The second development is the hybridisation of man and machine, where the supplementation and alteration of human flesh with machinic parts enhances the body.

### *Embodiment in cyberspace*

The illusion of disembodiment is played out on the assumption that bodily identities, the experience of bodies and embodiment are transferred into the machine.<sup>84</sup> London-based scholar, writer and cultural-critic Ziauddin Sardar observes that a specific condition of Western culture's relationship with technology is that it seeks a transcendental liberation

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<sup>76</sup> *Blade Runner* is a 1982 American science fiction film directed by Ridley Scott.

<sup>77</sup> *The Terminator* is a 1984 science fiction action film directed by James Cameron.

<sup>78</sup> *Dark City* is a 1998 neo-noir science fiction film directed by Alex Proyas.

<sup>79</sup> *The Matrix* is a 1999 science fiction-action film written and directed by Larry and Andy Wachowski.

<sup>80</sup> *eXistenZ* is a 1999 body horror/science fiction film by David Cronenberg.

<sup>81</sup> Featherstone and Burrows 1995, 3.

<sup>82</sup> Shilling 2005, 173.

<sup>83</sup> Shilling 2005, 173.

<sup>84</sup> Hayles 1999, 47.

from the body through a corporeal dissolution into machinery.<sup>85</sup> In her book *Architecture from the Outside: Essays on Virtual and Real Space* (2001) social and gender theorist Elisabeth Grosz sets out four regulating assumptions that govern how the idea of the dissolution of natural bodies (into virtuality) has impacted on the real: 1) the separation of virtual reality from the real and the material, the simulation from the original (seeing the one as the dematerialization rather the retranscription of the other); 2) the alignment of the real, historical city with the body and the virtual city of cyberspace with pure mind divested of bodily traces; 3) the linking of the 'real' or 'historical' city (the cities of the past) with the virtual or future city; and 4) the belief that the technological development of virtual communities and networks surpasses, displaces, and problematizes the body and, with it, identity and community as we currently know it.<sup>86</sup> As Grosz cautions, these assumptions 'are quite typical of the discourses surrounding VR [virtual reality] and cyberspace, which tend to be represented as a new kind of space unconstrained by the limits of corporeality.'<sup>87</sup> Along these lines of thought media artist and theorist Allucquère Rosanne Stone comments that despite the proportionate virtuality of the body in cyberspace, it is worth remembering that society's collective idea of the body 'originates in, and must return to, the physical. No reconfigured virtual body, no matter how beautiful, will slow the death of a cyberpunk with AIDS. Even in the age of the techno-social subject, life is lived through bodies.'<sup>88</sup>

### *Hybridisation of man and machine*

The academic and literary critic Katherine N. Hayles maintains that 'human corporeality blurred by technology' can be better understood by looking simultaneously at the 'power of simulation' and the 'embodied actualities' that produce it.<sup>89</sup> In the 1980s and 1990s a dense array of hybridisation strategies began to be provocatively tested in the works of performance artists Stelarc (Stelios Arkadiou), Stahl Stenslie and the mechatronic performances and installations by Catalan artist Marcel·lí Antúnez Roca. These artists

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<sup>85</sup> Sardar 1995, 36.

<sup>86</sup> Grosz 2001, 81.

<sup>87</sup> Grosz 2001, 81.

<sup>88</sup> Stone 1991, 113.

<sup>89</sup> Hayles 1999, 47.



shed light on to what it means to be human in the age where traditional social protocols are blurred by the protocols of machines. This type of technological confusion of the human body found its expression in the *cyborg*, described by Donna Haraway, a prominent scholar in the field of science and technology studies, as ‘a cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction.’<sup>90</sup> Haraway famously postulated in 1985 that ‘we are cyborgs’ - ‘fabricated hybrids of machine and organism.’<sup>91</sup>

At the same time Haraway theoretically formulated her ‘cyborg manifesto’ the Australian performance artist Stelarc, described as the ‘foremost exponent of cybernetic body art,’ has experimented with entangling the human body with technology, extending and augmenting human social relations via prosthetics and the Internet.<sup>92</sup> Events such as *Event for Amplified Body / Laser Eyes and Third Hand* in the Maki Gallery, Tokyo, performed on 2<sup>nd</sup> March 1986 have used fibre-optics and lenses, robot manipulators combining ‘real-time *gesture control* of the Virtual Arm, *pre-programmed* robot scanning *symbiotic* EMG activation of the Third Hand and *improvised* movements.’<sup>93</sup> As media theorist Gabriella Giannachi recollects, the viewer was involved in the performance in seeing ‘a variety of more or less choreographed and voluntary as well as involuntary movements, from both inside and outside Stelarc’s body.’<sup>94</sup>

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<sup>90</sup> Haraway 1991 [1985], 149.

<sup>91</sup> Haraway 1991 [1985], 150.

<sup>92</sup> Dery 2000, 577.

<sup>93</sup> Stelarc 1997, 247 [italics in original].

<sup>94</sup> Giannachi 2004, 58.



fig 3.09 Stelarc. *Amplified Body*. 1986.

Stelarc with cyborgian prosthetics at the *Event for Amplified Body / Laser Eyes and Third Hand* in the Maki Gallery, Tokyo.

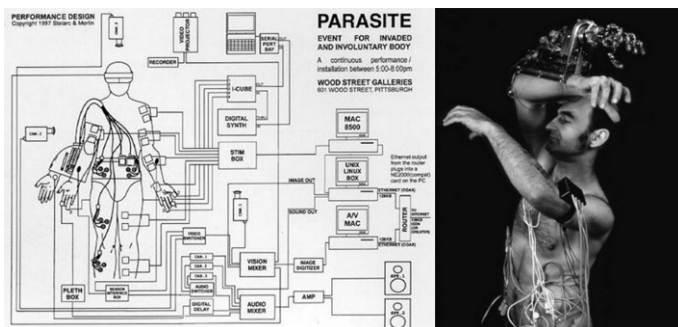


fig 3.10 Stelarc. *Ping Body*.1996; *Parasite*. 1997.

In *Ping Body* (1996) and *Parasite* (1997) Stelarc took his cyborgian extension further by connecting his body directly to the Internet. Describing his body as 'barometer of Internet activity' (1997, 27) Stelarc notes that 'instead of the body being prompted by other bodies in other places, Internet activity itself choreographs and composes the performance' (ibid.). In these spectacular performances, where the artist's body is linked to the net with a neuromuscular system and thrown into convulsive spasms as raw data downloaded from the web activated the body. Stelarc 'experienced the Internet as 'a kind of external nervous system' with which his 'cyborged body' has entered a 'symbiotic/ parasitic relationship.'<sup>95</sup>

<sup>95</sup> Interview with Gabriella Giannachi, Lancaster, 10<sup>th</sup> May 2002, quoted in Giannachi 2004, 60.

The discomfiting provocation of human corporeality by means of machine manipulation was often increased in the performances of Marcel·lí Antúnez Roca. Together with the computer artist Sergi Jordan Antúnez Roca presented with *Epizoo* (1994) an interactive performance in which the artist's body was strapped up into a mechatronic, pneumatic, kinetic exoskeleton, thus forced it to technoid subservience.

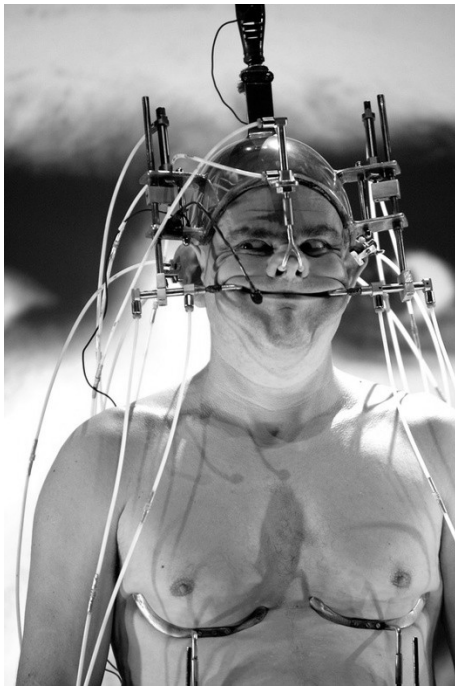


fig 3.11 Marcel·lí Antúnez Roca. *Epizoo*. 1994.

The orthopaedic robot mechanism is held to the body by two metal moulds, a belt and a helmet, into which the pneumatic mechanisms are fitted. These mechanisms can move the performer's nose, buttocks, pectoral muscles, mouth and ears while the artist remains standing upright on a rotating circular platform during the performance. The pneumatic devices are in turn connected to a system of computer controlled electro valves and relays. An exclusive application with an interface similar to a videogame is run by the computer. Its eleven interactive scenes include several computer generated animated sequences that recreate the figure of the artist and indicate the position and movement of the mechanisms. In this way the user can control the lighting, images and sound as well as the artist's body by using the mouse.<sup>96</sup>

The viewer is often empowered with the execution of the artwork. This circumstance is forthwith exploited to manipulate the premediated playful relationship between artist and viewer. The fusion of the biological, the human and the technological is staged by (ab)use and manipulation of another human body. During performances the spectator has lost 'on

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<sup>96</sup> Text taken from the artist's web site <http://www.marceliantunez.com/work/epizoo/>, accessed 12/11/2011.

occasion, all idea of his or her activity as the manipulator or the interface which makes it possible to move the devices attached to the artist's body, and, as a result, acts unconsciously as a torturer.<sup>97</sup> The fascination of conjoined flesh and machine performances might lie in the ambiguities that they provoke. Cultural theorist Joanna Zylińska observes that despite Stelarc's emphatic appraisal of the human body as 'obsolete body,' his own body, 'is still clearly a soft machine,' thus soft, organic and sensitive.<sup>98</sup> It is worth considering the possibility that the encounter of the prosthetic with the body might actually amplify the body's vulnerability. The problematic of understanding prosthetics as part of the body – to accept them on corporeal terms – is highlighted not only in the rather crude mechanical design of Stelarc's prosthetic machinery but also in Marcel·lí Antúnez Roca's performances, when he explains that 'the action of the "remote" agent is an aggressive action, which can harm and even wound the body which is on the receiving end.'<sup>99</sup>

A softer and corporeally more compliant approach was chosen by media artist Stahl Stenslie. When presenting *CyberSM* in 1993, the world's first full-body, tele-tactile communication system, he suggested to introduce 'flesh into the virtual dimension.'<sup>100</sup> Instead of abstracting the human body in the form of data or digital models to inject it into the virtual dimension, Stenslie, who is considered one of the founding fathers of Cybersex, proposes to formulate the prosthesis on corporeal terms.

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<sup>97</sup> Giannetti 1998, 19.

<sup>98</sup> Zylińska 2002, 562.

<sup>99</sup> Giannetti 1998, 19.

<sup>100</sup> Stenslie 1998, 25.



fig 3.12 Stahl Stenslie. *cyberSM*. 1993-94.

Through physical extension with tele-tactile sex machines physically distant people can stimulate one another, or feed their actions into the virtual dimension, while they themselves receive information, ie stimulation, from the distributed reality of cyberspace.

Working towards ‘tactile communication’ Stenslie laments in his essay ‘Flesh Space’ that ‘[r]arely is the virtual dimension mixed with bodily fluids and designed as holistic, multi-sensory experience.’<sup>101</sup> Instead of interfaces that restrict user experience - ‘visual simulation gives us only a small window into the virtual dimension’ - he proposes multi-sensory bodysuits.<sup>102</sup> These suits are fitted with tactile effectors (vibrators, heat pads) which impress the recipient with a sense of the effector’s bodily presence, and sensors (pressure sensitive joints, pressure pads) which in return allow the effector to sense the recipient.<sup>103</sup> Sensually corporeal stimulation in this realm of speculation offers a variety of experiences, ranging from stimulation of geographically remote bodies to exchanging stimulation with virtual creatures: notions that architectural soft machines are yet to embrace.

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<sup>101</sup> Stenslie 1998, 19.

<sup>102</sup> Stenslie 1998, 21.

<sup>103</sup> Stenslie admits that ‘technologically it is extremely hard to link man and machine in a non-obtrusive way’ but is looking forward to the arrival of ‘wetware like biochips, brain/ nerve implants, gentech and nanotech’ (1998, 21).

### s3 | Bodies projected outside themselves

*Shoe for Justine & Juliette (for walking in Slow Architecture)* – Corporeal reality – The human body in hybrid architecture – Gestuelpste bodies: the human body as inside-out generative tool

Developments in late twentieth century technology demonstrate a shift towards vitalist and often anthropocentric conceptions of artificial systems. An anthropocentric mandate applied to machines sees the body both as location and source of technology.<sup>104</sup> The art theorist Jonathan Crary asks, '[h]ow is the body ... becoming a component of new machines, economies, apparatuses, whether social, libidinal, or technological?'<sup>105</sup> In directing the question to the machine, the question would be: How is the machine becoming a component of bodies? As Chris Salter puts it: 'With the reigning machine paradigm for the technologized body forming the start of the twentieth century, the prostheticized, computationally augmented or *data-formed* body frames the twenty-first.'<sup>106</sup> In as much as the machine-connected and data-formed body revises the mechanized image of the body it does simultaneously and reciprocally instruct technology itself to become more human. A new alliance between technologized bodies and their equally talented architecture would provide an opportunity to re-write the anthropocentric mandate of architecture. Anthony Vidler observes in his text 'Homes for cyborgs,' '[n]ow the boundaries between the organic and the inorganic, blurred by cybernetic and biotechnologies, seem less sharp; the body, itself invaded and re-shaped by technology, invades and permeates the space outside, even as this space takes on dimensions that themselves confuse the inner and the outer, visually, mentally and physically.'<sup>107</sup> How then can architecture approach possibilities offered for extension in times of voluntary and involuntary relations with machines? How can architecture meet the body, which has been inverted into technology? Finding answers to these questions requires not only a better understanding of human ambitions for transcendence and associated ambitions for

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<sup>104</sup> Shilling 2005.

<sup>105</sup> Crary 1990, 2.

<sup>106</sup> Salter 2010, 221 [italics in original].

<sup>107</sup> Vidler 1992, 147.

invention, creation and modification, but also a deeper understanding of how technology reciprocates and incorporates human corporeality.

Ambitions for bodily dissolution into machinery seem to be an expression of humanity's eternal frustration with the limitations of the body, including its inevitable end. In an essay on the transcendent character of life the German sociologist Georg Simmel argues that human beings perceive of their corporeality through boundaries and limitations. Simmel pointed out that human beings seek to expand their sense of the world precisely because of the limitation of their physical capabilities. Simmel himself examines the telescope and the microscope as technological products of the human effort to transcend the body. Paradoxically, then, the body seems to be the source of its own transcendence. '[T]he primary phenomenon of life' seems to be dissolving the body into externalized prosthetics that are reaching beyond the body itself.<sup>108</sup> On one hand it is important to recognize that the technologization of the body tends to be played out on assumptions including the dissolution of the body into information, physical passivity of the (healthy) body and/or the primacy of the mind. On the other hand, as human flesh and sensibility are blurred by their own synthetisation through bio-invasive techniques (implants), sensors and prosthetics, the body inevitably becomes something that is alterable, connected and connectable to extra-corporeal systems.

### *Shoe for Justine & Juliette (for walking in Slow Architecture)*

I have designed a *Shoe for Justine et Juliette* (2007). The shoe is an experiment towards conceiving a soft machine as prosthetic, where the prosthetic learns from the body. The shoe presents a possibility for the protagonists of Marquises de Sade's novels *Justine, or The Misfortunes of Virtue* (1791) and *Juliette, or Vice Amply Rewarded* (1801) to encounter each other's world. In the *Dialectic of Enlightenment* (1973[1944]) Theodor W. Adorno and Max Horkheimer provide a discussion of de Sade's 'intransigent critique of practical reason.'<sup>109</sup> In the essay entitled 'Juliette or Enlightenment and Morality' they interpret the unheeding and calculating behaviour of Juliette as the embodiment of the philosophy of the

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<sup>108</sup> Simmel 1971 [1918], 356.

Enlightenment. Juliette's libertine philosophy 'makes the scientific the destructive principle. ... Justine, the virtuous sister, is a martyr for the moral law. Juliette embodies ... the pleasures of attacking civilization with its own weapons. She favours system and consequence. She is a proficient manipulator of the organ of rational thought.'<sup>110</sup>

The experimental shoe for Justine and Justine can be understood as a mechanical interpretation of Adorno and Horkheimer's *Dialectic of Enlightenment*. The shoe is accompanied by a short text.

Justine – who is familiar with every nuance of misfortune as she struggles to maintain her virtue in a world of sin – wears the shoe with the heel collapsed into the shoe. By unfolding her prosthetic heel she is able to assume the conditions of her sister, Juliette – who embraces the libertine philosophy that Justine shies away from and engages in virtually every form of depravity – by wearing the shoe with an extended heel. Juliette can collapse the heel of her shoe, thus assuming the state of Justine. The shoe enables Justine and Juliette not only to transgress their identities, but also to adapt to a slowly changing architectural environment.

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<sup>109</sup> Adorno, Theodor W. and Horkheimer, Max. 1973 [1944] *Dialectic of Enlightenment*. transl. by John Cumming. London: Allan Lane, 94.

<sup>110</sup> *ibid.*, 94-95.





fig 3.13 *Shoe for Justine et Juliette*. 2007.

General side view of shoe with foot harness and collapsible heel. Materials: leather, polyurethane rubber, steel, brass, gut string and resin.



fig 3.14 Rear view with collapsible heel.

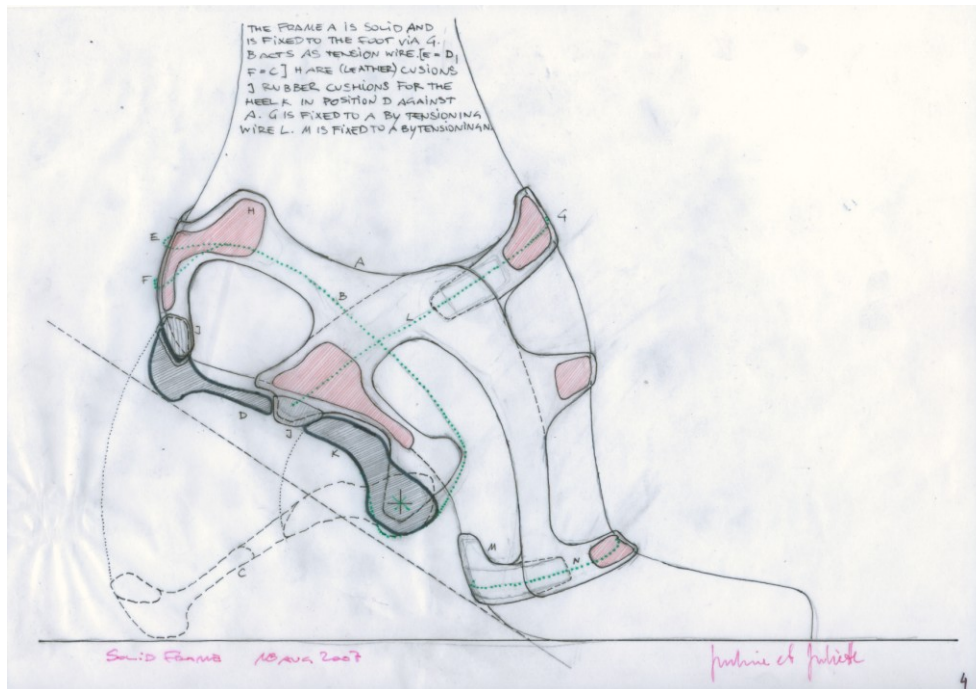


fig 3.15 Section drawing showing shoe with collapsed heel.

The harness (A) is fastened to the foot via tension wires (B,E,F,L,N) which are run through the harness and adjustable leather straps (M). The rubber cushion and the articulation surface (J) receive the heel (C) in its collapsed position.



fig 3.16 Detailed view of strapping.

The shoe is a liminal prosthetic that enables Justine to enter the world of Juliette and vice versa. Consequently the shoe has been designed and constructed to fit them both. The shoe operates in a world of multiple possibilities, where one object can be many by engaging with the transformative powers of mechanics; where the sensory takes precedence over the operational and where objects are constructed between meanings and purposes.

### **Corporeal reality**

Sociologists discussing opportunities provided by technology to extend or augment corporeal sensitivities and powers do not necessarily question the corporeal reality of the body. Chris Shilling clearly distinguishes between the artistic rhetoric of disembodiment and its social reality. Shilling theorises the body following the argument that every human relation is somehow expressed in the physical world and thus experienced through the body. In his book *The Body in Culture, Technology and Society* (2005), Shilling's concept of 'corporeal realism' is founded on the compelling view that while undoubtedly metaphorical and technological extensions of the body proper by way of technology offer new experiences and imaginations of the body, the physical reality of the body itself cannot and must not be denied. Shilling's 'corporeal realism' entails the recognition that both society and the body exist as real things, and not simply as ideas.

### *Body as source of technology*

According to Shilling, the body, as societal idea, is both a source as well as a location of technology.<sup>111</sup> He argues that, 'if the desire of embodied subjects for warmth, light and protection steered the uses of fire, and the concern for restoring physical mobility shaped the purpose and design of artificial limbs, we should be wary of dismissing the possibility that basic bodily needs continue to remain a *source* of technological innovation.'<sup>112</sup> 'Far from transcending the individual material flesh altogether, we can now see instead how these technologies remain grounded in, and constrained by, material bodily need: the body

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<sup>111</sup> Shilling 2005, 176-179.

<sup>112</sup> Shilling 2005, 175 [italics in original].

continues to steer their development.<sup>113</sup> As has already been demonstrated by the media philosopher Marshall McLuhan in *The Medium is the Message* (1962) the invention of technologies is a direct result of man's desire to extend his body and senses, evidencing strong affinity with the human desire for corporeal transcendence. While McLuhan's observations are associated with the extension of human beings through media, the extension strategy suggests similar possibilities for architecture – if it may be designed as an extension of the human body. Now, if architecture is conceived as machine that in turn is inspired by the human corporeality, there is the possibility that the machine may take over certain physical qualities, capacities and sensitivities and become, so to speak, 'corporeal' and perhaps even more human.

### **The human body in a hybrid architecture**

Georges Teyssot offers three hypotheses in his essay 'Hybrid Architecture: An Environment for the Prosthetic Body' (2005) to define and imagine architecture as 'an environment not just for "natural" bodies, but for bodies projected outside themselves, absent and ecstatic, by means of their technological extended senses.'<sup>114</sup> Teyssot developed the outline of the three hypotheses, a) the 'Body without organs' and b) the 'Organism' and c) the 'Organ without body' by drawing inspiration from French theatre and philosophy; most notably Antonin Artaud, Gilles Deleuze and Félix Guattari. Teyssot introduces the first hypothesis, the body without organs, reminding us that Deleuze and Guattari call for a body conceived as libidinal machinery, a 'desiring machine.'<sup>115</sup> This idea of the body would lead to the possibility of a 'body without organs.' Deleuze and Guattari expand in their later work *A Thousand Plateaus* (1987), that '[a] body without organs is not an empty body stripped of organs, but a body upon which that serves as organs (...) is distributed according to crowd phenomena. (...) Thus the body without organs is opposed less to organs as such than to the organization of the organs insofar as it composes an

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<sup>113</sup> Shilling 2005, 179.

<sup>114</sup> Teyssot 2005a, 81.

<sup>115</sup> Teyssot refers to Deleuze and Guattari's seminal work *Anti-Oedipus* 1983 [1972] where, according to Teyssot, they have extended Bataille's anthropological / psychoanalytic discourse of excess and transgression by the terms of technological/ cybernetic culture.

organism.<sup>116</sup> Deleuze and Guattari's caveat that the fantasy of the body without organs is unattainable: 'You never reach the body without organs, you can't reach it, you are forever attaining it, it is a limit.' recalls Simmel's observation that the limitations of the corporeal body are the source of its transcendence.<sup>117</sup> This debate is especially fascinating in relation to the reproduction of human capacities in machines.

On one side, according to Teyssot's first hypothesis, the body without organs is considering 'the body in its *exteriority*, in its relation to other bodies, perceived through relations of surfaces, differences, affects, desires.'<sup>118</sup> On the other side, the second hypothesis considers the 'reality' of the organism, 'conceiving the body only in its *interiority*, in its regime of internal distribution, where autonomous organs (de)compose the whole into multiple parts, breaking up its integrity.'<sup>119</sup> The 'organism' hypothesis installs a hierarchical order of systems in analogy to the biological hierarchy of organs. Organs are integrated in the complete regime of the organism, reflecting a regime of internal 'organisation', as is so essential for the legislation of the modernist architectural concept. As Teyssot expands, this logic is generally realised in 'organised' building typologies, such as hospitals. But 'it is also this type of functionalism that lies at the base of all "modernistic" architecture, which was nothing else than an application of organicism.'<sup>120</sup> In similar ways, Donna Haraway already showed in her seminal 1985 essay 'The cyborg manifesto' that the 'integrated organism' was typical for modernist thought but is now giving way to 'biotic components.'<sup>121</sup> This leads to the third hypothesis, which disengages the organ from the body.

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<sup>116</sup> Deleuze and Guattari 1987 [1980], 30.

<sup>117</sup> Deleuze and Guattari 1987 [1980], 150.

<sup>118</sup> Teyssot 2005a, 75.

<sup>119</sup> Teyssot 2005a, 75.

<sup>120</sup> Teyssot 2005a, 73.

<sup>121</sup> More specifically Haraway cautioned that '[t]he organism has been translated into problems of genetic coding and read-out. (...) In a sense organisms have ceased to exist as objects of knowledge, giving way to biotic components, i.e., special kinds of information-processing devices' (1991 [1985], 164). Haraway argued that cybernetic technologies blur the boundaries between humans and machines in that they reduce indiscriminately organic live and non-organic systems to electronically coded information that is exchangeable and reprogrammable.

### *Prosthetization of the body*

The organ without a body, however, is not a simple inversion of the body without organs. The organ without body is ‘released from the body [and] can be sold as a commodity, as well as “grafted on” to another body, another organism, be it living or not, be it mechanical, biological, or computational.’<sup>122</sup> The organ without a body is a ‘free organ,’ it might be an organic or a technological extension designed in reflection of specific bodily needs. The third hypothesis assumes an organ that does not need a body, yet it is not a body itself. As the organ without a body becomes part of the body as an extraneous entity, ‘it creates new regimes of regulation [and] new normalities.’<sup>123</sup>

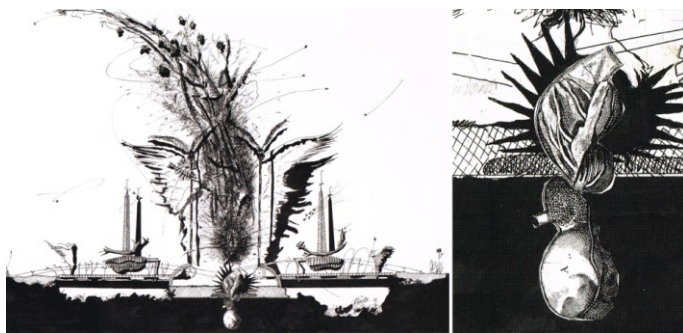


fig 3.17 Neil Spiller. Section of *Little Soft Machinery*. 2006.

*Little Soft Machinery* is a kind of semi-living creature that has grown from stem cells, an old testicle and a leaky bladder.<sup>124</sup> It rests underneath the Angel Gate, which is situated on an island in Fordwich, Kent. By a seemingly alchemic process the *Little Soft Machinery* produces the *vaz*, or holy gasoline. A grease-like substance is expelled when the bladder is full and it can no longer ‘resist the foot of Truth’ (ibid., 97).

Nowadays, the organ without body might be preserved in an ‘organ bank,’ or it might be an artificial prosthetic that is waiting for its body. Whilst prosthetics (one of architecture’s most misused metaphors) inevitably portrays the body as an incomplete being it simultaneously speaks of man’s endeavour to improve the body. If the prosthesis is seen replacing parts of, or adding parts to, the human body, it must inevitably conform structurally, systemically and aesthetically with the body. Academic and media theorist Marquard Smith and art historian Joanne Morra place a quotation of Bernard Steigler’s

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<sup>122</sup> Haraway 1991 [1985], 164.

<sup>123</sup> Haraway 1991 [1985], 164

<sup>124</sup> The project is part of *Communicating Vessels*, Neil Spiller’s extensive design and research project that ‘seeks to illustrate the far-reaching effects on architecture of biotechnology, virtuality and nanotechnology, and particularly the old division between landscape and architecture’ (Spiller 2008, 94-97).

*Technics and Time* (1998) as an epigraph to their introduction to *The Prosthetic Impulse* (2006). “The prosthesis is not a mere extension of the human body; it is the constitution of this body *qua* “human.””<sup>125</sup> As a marker of our cultural condition the prosthesis has become part of a contemporary technological imagination.

The conditioning of architecture by qualities of human/cyborged corporeality fundamentally informs the work of Marcos Cruz. By conceiving architectural interfaces as ‘inhabitable flesh’ Cruz proposes a strategy to understand architecture as an extension of the body.<sup>126</sup> Explaining his ‘Neoplasmatic Architecture’ theory in his book *The Inhabitable Flesh of Architecture* (2014) Cruz discusses in detail the prosthetic qualities of the game pods in Cronenberg’s sci-fi movie *eXistenZ*. Cruz maintains that the pods offer the possibility to understand the potential of hybridization of biological and synthetic systems for architecture.<sup>127</sup>



fig 3.18 David Cronenberg, Screenshot of *eXistenZ*. Canadian science fiction body film. 1999.

The movie’s protagonist Allegra Geller with a ‘game pod’ which is plugged into the gamer’s spine with an umbilical cord allowing the experience a physically holistic game reality.

The game-pod-player hybrid symbolizes the strategy to transfer corporeal qualities, sensuality and behaviour associated with living bodies onto artificial objects. The game pod, as a prosthetic organ, has become the leitmotif for a sensual and bodily experienced architecture. Cruz’s interpretation of these possibilities have manifested in projects such as *Hyperdermis/Cyborgian Interfaces* (2004-07), which was ‘informed by the conceptual image

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<sup>125</sup> Smith and Morra 2006, 152 [italics in original].

<sup>126</sup> Cruz 2014.

<sup>127</sup> Cruz 2014, 159.



of a cyborgian body [and] pursued the image of an interactive, networked and extended environment ... prompting the body to engage in an intensified manner with its physical surroundings.<sup>128</sup> As Cruz points out by reference to historian Mark Poster *Hyperdermis/Cyborgian Interfaces* is 'a liminal project, an interface between human and machine that invites penetration of each other.'<sup>129</sup>

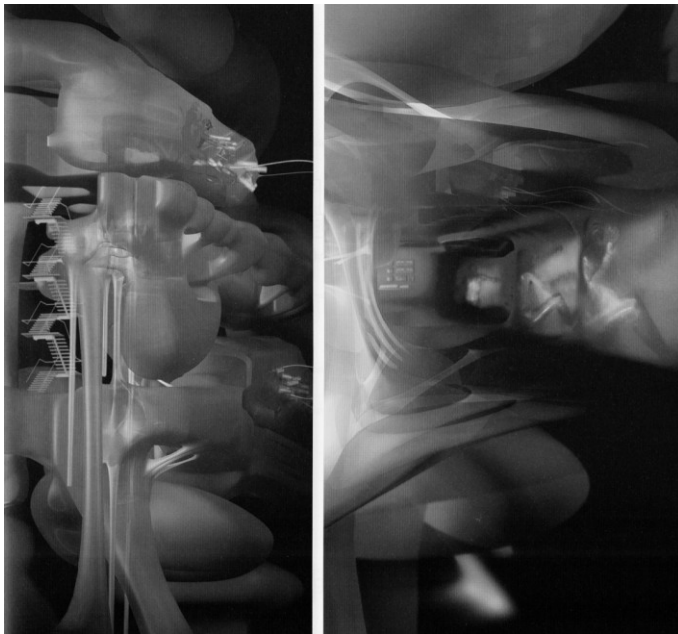


fig 3.19 Marcos Cruz. *Hyperdermis/ Cyborgian Interfaces*. 2004-07.  
Overall view from outside and internal view with communication area.

The prostheticization of the body does not only extend the corporeality of the body but also its imagination, as the anthropologist Sarah S. Jain notes in her important essay 'The Prosthetic Imagination' (1999). Smith and Morra note that 'to a perhaps worrying extent, the prosthetic has taken on a life of its own' and in pointing to Haraway's cyborg manifesto argue that the prosthetic has assumed an epic status as it is imbued with the ability to fulfil our ambition.<sup>130</sup> If the architectural machine is indeed discussed as a prosthetic to the human body, would its constitution be qua human? As the prosthetic

<sup>128</sup> Cruz 2014, 192.

<sup>129</sup> Cruz 2014, 192 and Poster 'Desiring Information and Machines' in Robert Mitchell and Philip Thurtle (ed.) 2004. *Data Made Flesh. Embodying Information*. New York; London: Routledge. pp 87-101. p 98.

<sup>130</sup> Smith and Morra 2006, 2.



specifies the delicate situation, the ‘*promise* of the humanization of technology’<sup>131</sup> shines onto architecture.

### **Gestuelpte bodies: the human body as inside-out generative tool<sup>132</sup>**

The art historian Elda Danese speculates in her essay, ‘Soft Machine,’ that the human is becoming more ‘machine’ *and* ‘software.’<sup>133</sup> She argues that the tendency to simulate and replace vital *human* functions with *artificial* systems shifts to the superposition of these two realities: ‘the attribution of softness to the machine indicates the identification of the automaton with the human body.’<sup>134</sup> The soft machine is a hermaphrodite of the human body and its expression through the machine. It has assimilated capacities, sensualities and sensitivities of both of them. We cannot think about one without the other.

Contemporary biological theory attributes traditionally human qualities to biotic components or ‘organ-machines,’ as Deleuze and Guattari describe them.<sup>135</sup> As a result,

the subject – produced as a residuum alongside the machine, as an appendix, or as a spare part adjacent to the machine – passes through all the degrees of the circle, and passes from one circle to another. This subject itself is not at the centre, which is occupied by the machine, but in the periphery, with no fixed identity, forever decentred, *defined* by the states through which it passes.<sup>136</sup>

Deleuze and Guattari have inverted the body-machine relation by describing it biologically (‘an appendix’) and mechanically (‘a spare part’). In extrapolating the distributed realities of bodies and machines on architecture one could argue that its anthropocentric mandate too has no centre anymore. It can no longer centre around the whole, skin-bound human body. The body – returning to architecture through technology – informs architecture

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<sup>131</sup> Smith and Morra 2006, 3 [italics in original].

<sup>132</sup> *Stuelping* is a neologism that describes the process of turning something inside out and is a neologism derived from the German verb ‘stülpen.’ The architectural application of this concept is explained in detail in c7. s1+2.

<sup>133</sup> Danese 2003.

<sup>134</sup> Danese 2003, 267.

<sup>135</sup> Deleuze and Guattari 1987 [1980], 149-165.

<sup>136</sup> Deleuze and Guattari 1983 [1972], 20 [italics in original].

with its corporeal capacities such as sensitivity, softness and dexterity. It has finally overcome its idealised naturalness contemplated through modernist productivity. The fundamental revision in favour of human corporeality extended by and transferred into technology advocates the conception of human sensibilities and capacities as being distributed through human artefacts. The body is metaphorically projected and inverted (gestuehlt) into the extraneous body of architecture.<sup>137</sup> Architecture is a peripheral machine without fixed identity. Its identities are many – vacillating in temporal flux without attitude.

## c3 | Conclusion

Architecture's organisation around the body as natural 'organism' has been revised in favour of an imagination of the body as source and location of technology's generative capacities. The body, as our biological primitive house, is affected by its co-existence with machines. Technologized body fantasies, from art performances to cyberpunk narratives, from extension/ augmentation fantasies to complete frustration with corporeal limitations, are inevitably challenging corporeal identities. However, problematically, these fantasies are often saturated with utopian optimism for technological progress while the physical reality of the 'real' body remains tied to its bio-determined characteristics.<sup>138</sup> Elizabeth Grosz emphasises that the predominant effect of recent technological advances has not been 'to transform bodies in any significant way – at least not yet – but to fundamentally transform the way that bodies are conceived, their sphere of imaginary and lived representation.'<sup>139</sup> In this sense identification with technologically active and activated, manipulative and manipulated bodies (instead of passive, abstracted, stereotyped ideals) is proposed in order to conceive of architecture as technoid extension in more corporeally holistic terms.

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<sup>137</sup> The figure of 'gestuehlt' bodies is experimented with architecturally by really soft machines and topological transformation projects in c7. s2+3 and c8.s1+2.

<sup>138</sup> See Timothy Lenoir's 'Techno-humanism: Requiem for the Cyborg' in Riskin 2007, 196-220.

<sup>139</sup> Grosz 2001, 51.

Contemporary architectural design might suffer from its evacuation of human bodies,<sup>140</sup> a development that is largely driven by digitalisation of design practice, which is in itself a consequence of translocation of social interactions from an environment designed around bodies [architecture] to virtual space designed for a ‘pure mind divested of bodily traces’ [cyberspace].<sup>141</sup> Anthony Vidler pointed out that the subsidence of the ‘human’ as generative instrument coincides with contemporary architecture focussing on topological issues.<sup>142</sup> ‘Now all trace of optical or bodily accommodation is removed in favour of “an abstraction based on process and movement;” and not the process and movement inherent to either the eye or the body, but rather one that is genetic, so to speak, to machine dynamics.’<sup>143</sup> But in positioning the machine in opposition to the human, Vidler excludes the possibility for heterogeneous exchange between them. Theorizing the body in conjunction with machines, on the other hand, enables an exploration of the ways in which technology has applied itself as an extension of the body: a plea for the return of the body – not as a cybernetic ghost, metaphorical cyborg or evacuated and meaningless meat-puppet but as an embodied being that lends its corporeal capabilities to a design of softer architecture (experimented with through the medium soft architectural machines). Human practices emerging from interaction with machines enrich ideas both of human corporeality and of technology. In turn, as architecture’s anthropological continuum has been disrupted by the entanglement of human practices with machines, ideas of the body as soft machine are presenting opportunities to enrich ideas of architecture. Not by giving precedence to idealised deterministic and functional notions but based on a transversal understanding of bodies and machines that gives precedence to the co-constituting and relational.

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<sup>140</sup> Cruz maintains that ‘[t]oday’s architecture has failed the body with its long heritage of purity of form and aesthetic of cleanliness.’ 2014, back cover.

<sup>141</sup> Grosz 2001, 81. See also Mallgrave’s neurological notes on computer design ‘dematerializing design thinking by removing it from sensory experience’ and ‘underutilizing the innate capacities of the human brain’ (2010, 215).

<sup>142</sup> Vidler specifies his critique: ‘[T]he notion of an architecture developed out of topologies rather than typologies ... introduces a fundamental rupture into theory if not into practice. For the generation of form from the outside, as envelope or skin, subjected to mathematically generated “force fields,” removes the humanistic subject definitely from all individual consideration’ (2000, 228).

<sup>143</sup> Vidler 2000, 228-9.

## c4 | Humanized bodies of architecture

Like a second sort of body – Surreal architectures of partial bodies – Pneumatic bodies

A body only exists to be other bodies.

William S. Burroughs<sup>144</sup>

‘When I blow up a balloon, I breathe my soul into an object...’

Piero Manzoni<sup>145</sup>

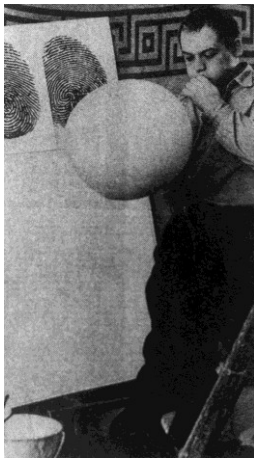


fig 4.01 Piero Manzoni. *Artist's Breath*. 1960.

By blowing up a balloon Manzoni not only animated an inanimate object. In as much as the inflation of the balloon with exhaled air instils the performance with pathos, it is the object's de- and inflation that symbolizes the life and decease of the human body – and also for relations of human beings with their artifacts.<sup>146</sup>

### Introduction

Architecture's reflection of that what is human can be examined through the ways architects intend their designs to respond to or interact with human beings. Historically, thinking 'architecture with our bodies, [just as] we think our bodies through architecture'...

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<sup>144</sup> Burroughs 1971, 26.

<sup>145</sup> Manzoni in Pichler 1998, 186. Orig. quote (1960) in German: 'Wenn ich den Ballon aufblase, hauche ich meine Seele in einen Gegenstand ...'

<sup>146</sup> The remnants of the balloon are kept in the Tate Modern archives (Ref. T07589).

'has long been a tradition of architectural theory,'<sup>147</sup> as Marco Frascari maintains, but these metaphorical notions have now been altered by technologically blurred and extended architectures capable of responding dynamically to human needs through more direct and immediate terms of interaction. Based on the hypothesis that architecture is human-centred (anthropocentric), architectural environments can be conceptualized in collaboration with the human body *through* technology, offering the opportunity to incorporate corporeal sensitivity, softness, sensuality and closeness as characteristics that emerge not between humans alone, but between humans, machines and architecture. Maria Luisa Palumbo insists that ascribing human characteristics to architecture, is a consequence of its technologisation. By alluding to reciprocities between technology, architecture and human bodies, Palumbo evokes what she terms 'corporeal architecture.'<sup>148</sup> Palumbo points out that '[i]t is difficult to deny that through the possibilities offered by electronics, architecture tends to become a body, to become animated and develop that capacity for sensitivity, flexibility and interactivity that is the very essence of the living body.'<sup>149</sup> Along these lines Braham and Emmons maintain that characteristics of human corporeality, such as dynamics and sensitivity increasingly inform the imagination of buildings as 'flexible systems.'<sup>150</sup> The reflection of that which is human in systems, devices and machines installed in architecture also provokes an interrogation of the motives for, and manifestations of, anthropocentric speculations about architectural space.

### *Chapter overview*

Section 1 explores how architecture has developed a new line of anthropocentrism based on the premise of a technological assimilation of the human body. Taking as a starting point George Teyssot's essay 'Hybrid Architecture: An Environment for the Prosthetic Body' (2005a), I discuss the assimilative powers of technology, and the ways in which such approaches conceptualize architecture as 'a second sort of body.'<sup>151</sup> Speculations

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<sup>147</sup> Frascari 1991, 1.

<sup>148</sup> Palumbo 2000, 66.

<sup>149</sup> Palumbo 2000, 65.

<sup>150</sup> Braham and Emmons 2002, 292.

<sup>151</sup> Teyssot 2005a.

about the theoretical spaces of bodies, machines and architecture explore how the human body as soft machine can inform architectural design as a generative design tool. The section moves closer into the soft machine heterogeneity by looking between the two seemingly impossible terms ‘soft’ and ‘machine.’

From here onwards, the chapter takes a look at two distinct historical precedents of exploring close corporeal analogies in architectural design. These are, in section 2, the surrealist’s dreams of biomorphic architectures composed of ‘partial bodies,’ ‘psychoanalytical furniture’ and ‘wet walls.’ The speculative inhabitation of Le Corbusier’s *Villa Savoye* and Kiesler’s *Endless House* by Hans Bellmer’s infamous puppé informs a comparative case study of the secret role of the human body to inform ideas of architecture ‘as a living organism that can be inhabited and engaged by the body.’<sup>152</sup>

Following on from un-materialised surreal fantasies, section 3 discusses Coop Himmelb(l)au, Haus-Rucker-Co and the French Utopie group’s attempts during the pneumatic euphoria of the 1960s and 1970s to infuse space with the exorbitant freedom of human bodies in projects such as *Yellow Heart* (1968), *Mind Expander* (1967), *Heart City* (1969). The chapter concludes with some case studies of transformable pneumatics explored by architects Mark Fisher, Nicolas Negroponte, Sean R. Wellesley-Miller and Kas Oosterhuis’ Hyperbody Research group. The chapter can be read as prolegomena to chapter 8, with regards to the transference of ideas from utopian visions to enabling technologies.

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<sup>152</sup> Philips 2005, 152.

## s1 | Like a second sort of body

Assimilative Technology – Impossible meanings – Soft mechanization takes command  
– Soft Machine Architectural Design

The technological reflection of human sensitivity and corporeality in architecture encourages conceiving of buildings as a bodies. By the time Reyner Banham demonstrated the impact of technology on architectural design in his seminal book *The Architecture of the Well-Tempered Environment* (1969) architecture has already been given the capacity to respond to distinctive parameters of human inhabitation by adjusting temperature, humidity and oxygen levels.<sup>153</sup> Since then, the incorporation of systems, sensors, regulators and machines has enabled architecture to develop a concept of anthropocentrism based on the premise of a technological assimilation of the human body. Steven Gage, British architect and founder of the *Interactive Machine Workshop* at the Bartlett, UCL, observed that ‘buildings are infiltrated by mechanical and electrical machinery and systems and this is profoundly affecting our experience of their architecture.’<sup>154</sup> Responding to these developments, architectural designers have incorporated reciprocities between notions of the corporeal and machines in their design practices, as Peter Cook’s writes in his text ‘Buildings as Machines’ that by designing architecture as ‘building-as-machine,’ the design becomes a hybrid of ‘machine’ and ‘flesh.’<sup>155</sup> The buildings-as-body, according to Palumbo has become ‘capable of being aware of its own alterations (e.g. a state of structural strain), capable of contextual awareness (being aware of environmental alterations or the presence of a human being), as well as reacting by activating appropriate behaviours.’<sup>156</sup> The capacity of technology to create what George Teyssot calls ‘tools and instruments like a second sort of body’<sup>157</sup> or Marshall McLuhan’s famous claim that technology can be an ‘extension of our bodies and

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<sup>153</sup> Banham 1984 [1969]. For an extensive anthology of the influence of technology on theory and design of architecture, see Braham and Hale 2007.

<sup>154</sup> Gage 1998, 81.

<sup>155</sup> Cook 1996, 33.

<sup>156</sup> Palumbo 2000, 66.

<sup>157</sup> Teyssot 2005a, 81.

senses,<sup>158</sup> – clothing as an extension of skin, housing as an extension of the body's heat-control mechanism, etc. – can be positioned as an intellectual point of departure for discussing architecture as an extracorporeal extension of the body.

### **Assimilative Technology**

Luis Fernández-Galiano argues that by translating the technological expression of the human body into architecture, architecture itself can be thought of as existing outside of the body as 'an exosomatic artefact of man.'<sup>159</sup> Whether this is seen in hydraulic terms, where for instance the sewer system, with its tubes and treatment plants, is the technological extension of the gastro-intestine tract (with the toilet bowl being the culturally engineered interface) or in electronic terms, where the screen is engineered to meet the spectrum of the eye; the medium through which all exchange is facilitated is the human body. The endeavour to infuse architecture with qualities of the body – be they geometrical, symbolical, behavioural or physical - might be as old as architecture itself.<sup>160</sup> Today, the relation between the human body and the artefact it creates is no longer restrained by mechanistic, spiritual or functional conceptions. If architecture is seeking within its own physique an image of the human body then the assimilation of the human body might not be limited to morphological criteria but extended on a technological level. George Teyssot proposes in his essay 'Hybrid Architecture: An Environment for the Prosthetic Body' that, '[f]ar from assimilating the tool with the body according to the mechanistic tradition of Cartesian dualism, we must conceive tools and instruments like a second sort of body, incorporated into and extending our corporeal power.'<sup>161</sup> In Teyssot's terms architecture's intimate alliance with machines is mediated through the human body. His observation about the assimilative power of technology points towards a new architecture as a second body: an architecture that converges with an organically networked, technologically symbiotized body. How then can the theoretical space of bodies, machines and architecture be explored?

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<sup>158</sup> McLuhan 1964, 123.

<sup>159</sup> Fernández-Galiano 2000,70.

<sup>160</sup> Feuerstein 2002.

<sup>161</sup> Teyssot 2005a, 81.



## Inpossible meanings

Conceiving of the human body in terms of its invasion, assimilation and extension by technology has afforded new ways to think about architecture. The body's co-presence and co-evolution with machines has inspired a humanisation of technology. But the fantasies of human body as soft machine<sup>162</sup> and the traditional machine softened by its interaction with human bodies<sup>163</sup> have established an in-between space which can be explored by looking between the two seemingly incompatible terms 'soft' and 'machine.' On the one hand there is softness, connoting of comfort and tenderness but also passive notions of yielding, adopting and assuming. On the other hand there is the machine, bringing to mind notions of efficiency, power and change but also repetition, lack of self-determination and inability to think or feel.

### *Chiasm of softness and machine*

The inherent *passivity* of softness contradicts the potential *activity* of the machine. The incompatibility is similar to signs pointing in two different directions, while remaining attached to the same signpost.

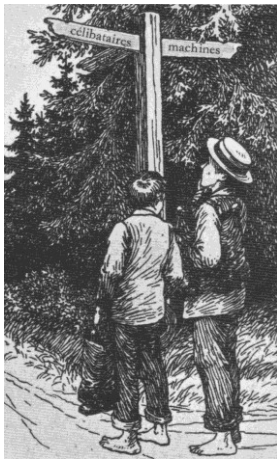


fig 4.02 Sign post with 'bachelor' and 'machine' pointing into different directions while being attached to the same sign post.<sup>164</sup>

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<sup>162</sup> Burroughs 1961.

<sup>163</sup> Simmel 1918; McLuhan 1964; Banham 1969, Teyssot 2005a.

<sup>164</sup> Szeemann 1975, 17.

Another analogy makes reference to Maurice Merleau-Ponty's concept of the chiasm, which he uses as an analogy to discuss the ambivalent relation of the ambition for exchange and the impossibility of exchange.<sup>165</sup> Similar to the optical chiasm of our brain, where the optical nerves partially cross, information coming from seemingly disparate directions is intertwined, overlaid and exchanged.

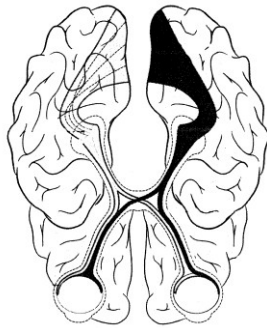


fig 4.03 Optical chiasm.

Taking intellectual departure from Merleau-Ponty's metaphor of the chiasm, softness and the machine, although seemingly coming from disparate directions are intertwined, overlaid and exchanged. The chiasm of the divergent meanings of 'softness' and 'machine' creates unconditional relations where softness is infused into the machine [c5. Mechanics of softness] and the machine is infused into softness [c7 Really soft machines].

### *Oxymoronic properties of soft machines*

In Ancient Greek *oxus* means 'sharp' and *moros* means 'dull'. Combined and taken as a metaphor they are 'the rhetorical figure in which two antithetical words are pitted against each other.'<sup>166</sup> But oxymorons are not only present in language: we can also find them in visual or physical manifestations. Patrick Hughes points out that the physical manifestation of a thing in the visually perceivable world can have oxymoronic properties,

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<sup>165</sup> Merleau-Ponty refers to the impossibility of exchange between two self-aware individuals. '...what announces itself to me as being appears in the eyes of the others to be only "states of consciousness." - - But, like the chiasm of the eyes, this one is also what makes us belong to the same world - a world which is not projective, but forms its unity across impossibilities such as that of *my* world and the world of the other...' (1968, 215).

<sup>166</sup> Hughes 1984, 15.

where the material quality is contradictory to the purpose of the object, seeming to deny its nature.<sup>167</sup>

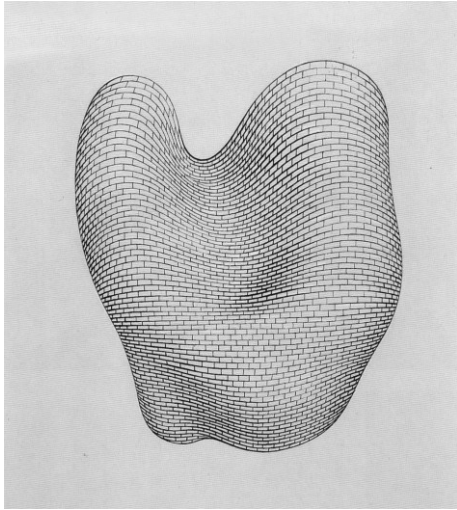


fig 4.04 Hans Bellmer. *Corset-Bastille*. 1943.

A brick wall is given the contours and curvatures resembling parts of the human body. The distortion of the rectangular geometry of bricks transforms not only the conventional idea of the brick as unified building block of a static wall, but also evokes the idea that the brick wall undergoes dynamic undulations or convulsions.



fig 4.05 Claes Oldenburg. *Giant Soft Fan*. 1967.

Oldenburg's other 'soft machines' include a drum set, soft scissors, a soft toilet, and a soft telephone.

In the arts the oxymoron is exploited by juxtaposing the impression of the work of art with the traditional understanding of its content. This can be exemplified in Hans Bellmer's eroticising aberration of the human body, for instance, when he applies

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<sup>167</sup> Hughes 1984, 47.

properties of the human body to objects as for example in his illustration *Corset-Bastille* from *Petite anatomie de l'inconscient physique ou l'anatomie de l'image* (1957), where the hardness of the brick wall is contradicted by the sensual curvature of the human body. As David Porush puts it in his observations of literature produced in the cybernetic age, *The Soft Machine: Cybernetic Fiction* (1985) the metaphor derives its appeal 'from its oxymoronic properties, the image of a machine softened by art.'<sup>168</sup> American sculptor Claes Oldenburg made a number of sculptures in his *Soft Machine* series contradicting the object's purpose with its materiality. If the oxymoronic method is applied to architecture – the illusion of softness attained through hard materiality – this notion highlights architecture's fundamental oxymoronic condition: that it seeks to envelop a sensitive, motile, dependent and soft being with static, hard and immutable materiality.<sup>169</sup>

### **Soft mechanization takes command**

The paradox of the soft machine could be used to speculatively change previous assumptions of architectural design and theory and overcome the myth of dehumanisation and displacement of human values by the agency of machines. The negative connotations of technology have been a reoccurring theme in the sociology of the twentieth century. In his book *The End of Modernity* Italian philosopher Gianni Vattimo observes that the relationship between the embodied subject and the world has been forever changed by a machined modernity. Vattimo states that '[t]echnology appears as the cause of a general process of dehumanization that includes both the displacement of humanistic cultural ideas in favour of modelling the human subject based on the sciences and on rationally controlled productive capacities, and a process of accentuated rationalization at the level of social and political organization that reveals the features of the wholly administrative and regulated society.'<sup>170</sup> The architectural slogans echoing these processes were Le Corbusier's 'a house is a machine for living in.' (1923), Siegfried Giedion's 'mechanization takes command' (1948) and Banham's architecture as an

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<sup>168</sup> Porush 1985, 99.

<sup>169</sup> The incompatibility of soft forms and hard materials can be found throughout architectural history in styles such as Baroque (Johann Bernhard Fischer von Erlach), Art Nouveau (Hector Guimard and Antoni Gaudí) to the contemporary oxymoronic struggle of digital formalism.

<sup>170</sup> Vattimo 1988, 34.

‘environment of the machine aesthetic’ (1969). If, for a moment of un-tethered imagination the soft machine would lend its oxymoronic properties to a suggestive re-reading of these architectural slogans of modernity, *soft* mechanisation would take command, architecture would be an environment of the *soft* machine aesthetic and the house would be a *soft* machine for living in.

In his essay ‘The Work of Art in the Age of Mechanical Reproduction’ (1936) the German cultural critic Walter Benjamin maintained that the struggle to resolve humans’ ambivalent relations with machines – productivity versus creativity – was one of the stronger undercurrents of modernity.<sup>171</sup> In contrast and often in fierce rejection of modernist architectural ideals, surrealism attempted but never succeeded, to establish alternative and more inclusive architectural relations between technology and human corporeality. Visions of biomorph shapes forming symbiotic relations with human beings inspired ideas of architecture as ‘living machine,’<sup>172</sup> as articulated by Frederick Kiesler in his manifesto ‘On Correalism and Biotechnique.’ The oxymoronic entanglement of life and machines appealed to technology to act, not as a dehumanizing force, but as a humanizing force. Having been published in 1939, almost a decade before Giedion’s mechanical retrospective ‘Mechanization takes Command,’ Kiesler’s correalism manifesto held the promise for an architecture as a kind of second body, capable of reciprocating human sensitivities and capacities through symbiosis of biomorphic form and technology.

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<sup>171</sup> Benjamin 2008 [1936].

<sup>172</sup> Kiesler 1939, 64+71.

## s2 | Surreal architectures of partial bodies

The intrauterine appeal of anthropomorphic architecture – New desires and corporeal anagrams – Biomorphic corporeality – Shifted anthropocentrism

Some of the most radical attempts to re-conceptualise the relations between the human body, machines and architecture have been undertaken by architects, painters and writers associated with the surrealist movement. Architects, writers and artists, such as Frederick Kiesler, André Breton, Tristan Tzara and Roberto Matta, established surrealism as a new order *against* the modernist mantra for standardisation, functionality and efficiency.<sup>173</sup> Despite often drawing on similar sources of inspiration as their modernist contemporaries, they articulated architectural visions that aspired to be more inclusive of corporeal sensualities. The idea that artificial form has to follow the logic of industrial production was not acceptable to the surrealists. Instead they sought an entanglement of technology and form that embraced the human body as generative tool infusing architecture with a sense of symbiosis and intimacy. Through extending the imagination of the human body, the surrealists developed utopian ideas of architectural bodies. The fascinating variability and freedom of human bodies also offered new pathways to resolve surrealism's ambivalent attitude towards technology. Rather than conceptually mechanizing the body as if it were part of a machine, the surrealist mentality embraced the human body by expanding and exaggerating its capacities and desires in order to reflect them onto the design of the artificial realm, whether in the form of machines, objects, paintings or architecture.<sup>174</sup>

A discussion of surrealist ambitions to infuse space with the freedom and sensuality of human bodies contributes to this thesis for two reasons. Firstly, surrealist visions of architecture conceived as body can be read as visionary precursors of the anthropocentrism inherent in some of 1960s projects of Coop Himmelb(l)au, Haus-Rucker-Co and the French Utopie group, which will be discussed in the next section, titled 'Pneumatic bodies.' Lacking enabling technologies such as pneumatics, which

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<sup>173</sup> Architectural theorist Thomas Mical maintains that there lies 'a secret history of surrealist thought' within modern architecture. See Mical 2005, 8.

<sup>174</sup> See Malt 2004 for a discussion about the productive reciprocity between object and body in Surrealism.

became the suitable medium for the utopian spirit of the 1960s,<sup>175</sup> surrealists celebrated architecture's symbiosis with human corporeality with fantastic but un-built visions of biomorphic form. Secondly, surrealist visions of architecture composed of partial bodies or 'living machine' also provide a historical context for my own speculations about an 'embodied architecture' composed of 'morphodynamic primitives,' which I will discuss in chapter 7. Emanating from the thesis that surrealism's response to what André Breton came to call the 'crisis of the object' was driven by ambitions for a humanisation of architectural form, I discuss works of Kiesler, Tzara and Matta, locating a provocation of desires and sensualities through architecture that would normally be associated with human bodies themselves.

### **The intrauterine appeal of anthropomorphic architecture**

Surrealists believed that human beings could relate more intuitively to biomorphic forms than to geometric abstraction.<sup>176</sup> André Breton, in his seminal lecture *Situation surréaliste de l'objet* (1935), dismissed the cold rationalism of Le Corbusier's *L'esprit nouveau* and instead valorised the fantastic, the poetic and the pre-symbolic, which in his view had already been established by the Modern Style (Art Deco) around 1900. Breton detected the 'fundamental crisis of the object' implying that surrealism had to find a new orientation in relation to the physical properties of the world.<sup>177</sup> A new 'connaissance' of reality should stimulate a modification of the object in order to reveal its hidden potential and latencies. The 'staggering of the intimate order of the real', to take a phrase from Ferdinand Alquié's *The Philosophy of Surrealism* (1965), was to become the premise for the entire surreal project.<sup>178</sup> The external object may become an extension of our *self* in order to deviate from the real.<sup>179</sup> But in the 1930s, despite Breton's enthusiastic lectures and texts, the

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<sup>175</sup> Conolly et al. 1968.

<sup>176</sup> Fletcher 1992, 239-241.

<sup>177</sup> Breton's essay 'Crise de l'objet' (1936), reprinted in Waldberg 1965.

<sup>178</sup> Alquié 1965, 33.

<sup>179</sup> Alquié continues Breton's thought: 'There is no more question of reconstructing the World technologically by submitting to objective laws [and] ... mechanical processes differing from those by which Nature made them; we aspire to an upheaval, which as it transformed the World would at the same time change life (ibid.).

movement was struggling to find a corresponding expression in architecture comparable to the new arenas opened up, for instance, in painting, sculpture and film.<sup>180</sup>

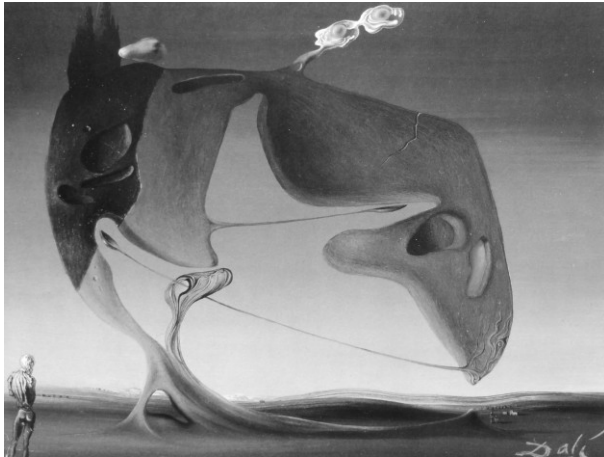


fig 4.06 Salvador Dalí. *Surrealist architecture*. 1932.

Aligning with Breton, the Romanian/ French writer and poet Tristan Tzara wrote in *Minotaure* no. 3-4 (1933) in a short article titled ‘On a Certain Automatism of Taste’ against modernist aesthetics (‘as hygienic and stripped of ornaments as it wishes to appear’) in favour of an architecture with an intrauterine appeal, calling for a ‘dwelling place [that] symbolizes prenatal comfort’ provided by ‘soft tactile depths ... of pre-natal desires.’<sup>181</sup> The surrealist gusto for Freudian theories of the unconscious instilled architecture with a new sensibility. The Bretonian *crise d’objet* vis-à-vis the self was resolved in architectural terms by inverting the human body onto the object. The surrealist obsession with the female body has reproduced the embodiment of thresholds – its architectural project *per se* – with the imagery of the feminine.<sup>182</sup>

In his article Tzara evokes architectural forms, like the cave, the grotto and even ‘the igloo of the Esquimaux’, as bearers of circular, spherical and irregular forms that express tactile

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<sup>180</sup> As Haim N. Finkelstein explains in *Surrealism and the Crisis of the Object*: ‘There is no surrealist architecture in the strict sense of the term. On the whole, architectural projects planned by surrealist artists, or by architects related to the Surrealist Movement, seldom left the drawing board’ (1979, 111). One of the most popular manifestations of ‘surrealist architecture’, Salvador Dalí’s *Dream of Venus* pavillion at the New York World Fair 1939 was not architecture *per se* but space fitted with objects, mannequins, etc. It provides the classic example how a ‘fantasy’ interior is mistaken for surrealist architecture in the popular imagination.

<sup>181</sup> Tzara 1933; transl. in Marcel 1980, 337.

<sup>182</sup> Stone-Richards 2005, 268.



and haptic properties in the built environment. In contrast to ‘modern’ architecture, which for Tzara is the ‘complete negation of the image of habitation’<sup>183</sup> these organic forms are associated with the ‘haptic depths’ of interiority, most notably the uterus of the mother, and Tzara postulates that ‘the dwelling symbolises prenatal comfort ... [and] the architecture of the future will be intrauterine.’<sup>184</sup> Anthony Vidler observed of Tzara’s uterine visions, that ‘[e]ntered through “cavities of vaginal form,” these conical or half-spherical houses were dark, tactile and soft.’<sup>185</sup> In continuation of these bids for architecture’s inclusion of human embodiment the young Roberto Matta, five years after leaving Le Corbusier’s office<sup>186</sup> argued vividly in his article ‘Sensitive Mathematics – Architecture of Time’, published in what turned out to be the last issue of *Minotaure* (no. 11, May 1938), for a humanization of architectural form: ‘We must have walls like wet sheets that get out of shape and fit our psychological fears; arms hanging between switches that throw a light barking at shapes and at their colored shadows, able to wake up the mouth’s gums themselves like sculpture for lips ...’<sup>187</sup>

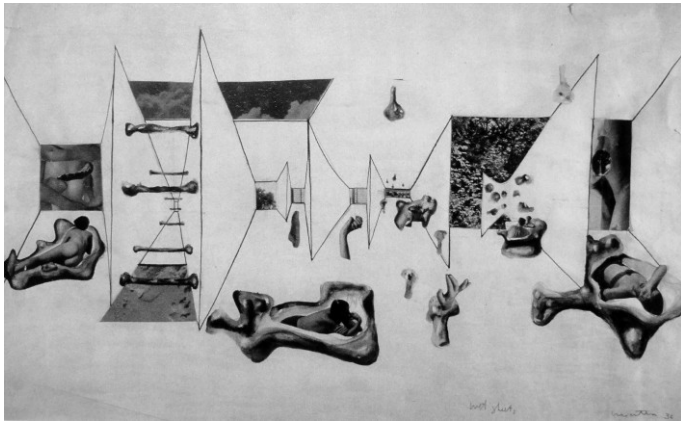


fig 4.07 Roberto Matta. *Wet Sheets*. 1936.

<sup>183</sup> Original French ‘la négation complete de l’image de la *demeure* [italics in original] Tzara 1933; transl. in Marcel 1980, 337.

<sup>184</sup> Tzara 1933; transl. in Marcel 1980, 337.

<sup>185</sup> Vidler 1992, 151.

<sup>186</sup> Matta (full name Roberto Sebastián Antonio Matta Eschauen), although widely known for his paintings, trained as an architect in his native Chile, and worked as a designer in Le Corbusier’s office in Paris, though he never shared the rationalistic views of his onetime employer (Jean 1980, 337). Matta lived in Paris from 1933, where he was introduced to the work of Picasso and Duchamp and is believed to have wholly rejected architectural practice for painting in 1937 (Pablo Picasso and Joan Miró were credited with effecting this change) (Goizueta 2004, 15) before emigrating to New York in 1939 (ibid., 21).

The article is accompanied by the imaginative drawing *Wet Sheets* (1936) that proposed an organic intrauterine apartment.<sup>188</sup> Matta's architecture of 'wet walls', 'appetizing furniture' and 'objects of total freedom that would be like plastic psychoanalytical mirrors'<sup>189</sup> describes an anthropomorphic architecture composed of partial bodies, an architecture in anticipation of bodies, eroticised by the use of a vocabulary that we use to describe the more sensitive parts of the human body.

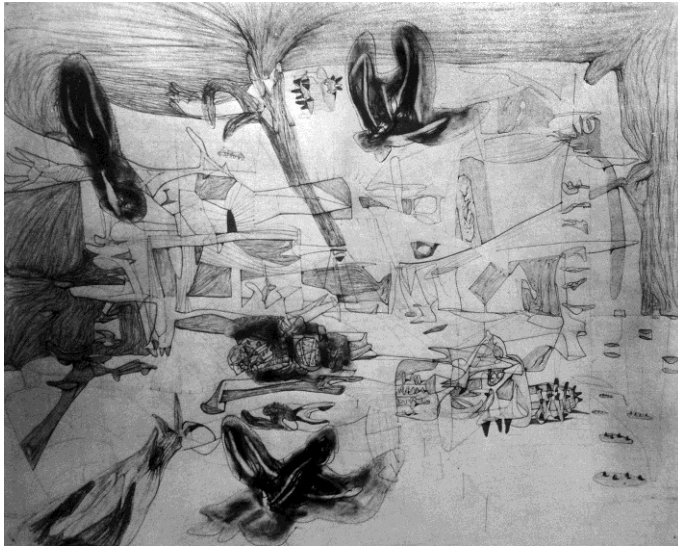


fig 4.08 Roberto Matta. *Psychological Architecture*. 1940-41.

As Marcel Jean observes in his edition *Autobiography of Surrealism* Matta was in search for 'new and more "livable" shapes in human dwellings, satisfying unconscious desires as well as material needs.'<sup>190</sup> Matta's project was certainly one of the most ambitious attempts to resolve the *crise d'object* in the realm of architecture at that time. In fact, 'Matta's surrealist colleagues, though no less intent upon tapping the irrational and the poetic than Matta himself, harbored highly negative predispositions towards the practical limitations of architecture.'<sup>191</sup> Similarly, Bernhard Tschumi would later note in *Architecture and its Double*, that for surrealism in general '[r]eal spaces were less important than the symbolic images

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<sup>187</sup> Original French in Matta 1938, 43; transl. in Jean 1980, 338.

<sup>188</sup> See catalogue of *The Surreal House* exhibition at the Barbican, London; Alison 2010, 206.

<sup>189</sup> Original French in Matta 1938, 43; transl. in Jean 1980, 338.

<sup>190</sup> Jean 1980, 337.

<sup>191</sup> Cernuschi 2004, 54.

they contained.<sup>192</sup> And thus, regrettably, the architectural vision of the early Matta would remain a utopian fantasy. We can only speculate how Matta would have attempted to realize his visions of ‘wet walls’ and ‘psychoanalytical mirrors’, or how Tzara would have created an ‘intrauterine’ architecture. They might have imagined them as a hybrid coincidence of bodies and machines. Their utopian ideas, however, have provided a breeding ground for ideas that would be further developed conceptually and experimentally by their friend,<sup>193</sup> the Austrian architect Frederick Kiesler.

### New desires and corporeal anagrams

As Kiesler puts it in his own words, the *Endless House* (and in that sense architecture) is a ‘living organism, not just an arrangement of dead material: it lives as a whole and in its details. The house is the skin of the human body.’<sup>194</sup>

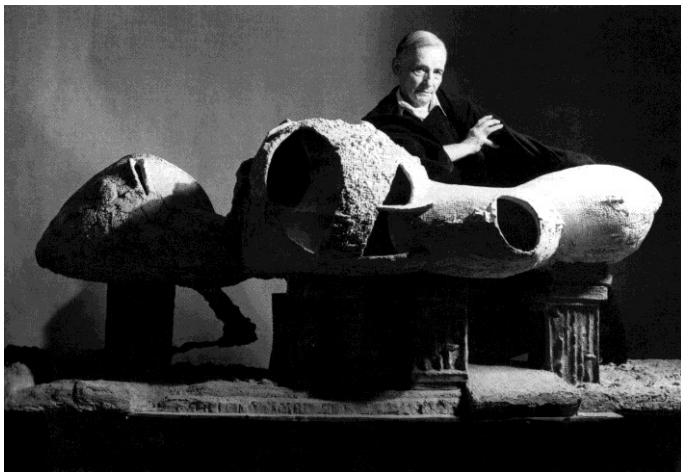


fig 4.09 Frederick Kiesler with the model for the *Endless House*; around 1960.

Kiesler anticipated nothing less than the innovation of a new type of living: a radicalism of ideas as a manifestation of the power of architecture to invent new desires by changing the way we coexist and inhabit architecture.<sup>195</sup>

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<sup>192</sup> Tschumi 1990, 112.

<sup>193</sup> Tzara and Kiesler have known each other since 1924. Matta and Kiesler became acquainted in the 1940s.

<sup>194</sup> Frederick Kiesler in ‘Manifeste du Corréalisme’, *L’architecture d’Aujourd’hui* (June 1949). The manifesto was first published in *Architecture d’Aujourd’hui*, Paris 1949 and can be found in facsimile in the back of Bogner 2001.

The idea of the house as skin provokes architecture to be like the body and we hear at the same time Matta's 'wet walls' and Tzara's 'intrauterine architecture' echoing in this statement. The stark contrast between the modernist treatment of the body by functionalism and the Surrealist obsession with its sensuality is illustrated by Thomas Mical's fantasy of Hans Bellmer's puppée inhabiting a LeCorbusian villa: 'an objectified body of fragments inhabiting a sanitized "machine for living"'<sup>196</sup> Reyner Banham has already observed that the re-discovered body of the modernist movement and the new architecture to house it

are clear aspects of the same vision, yet they seem to have no organic relationship. Standing upon a terrain idéal, not our common earth, each is a free-standing conception, absolute and unconditioned by the other, bathed by the same sun, but that sun does not shine through the windows of the ideal building into the eyes of the ideal body ...<sup>197</sup>

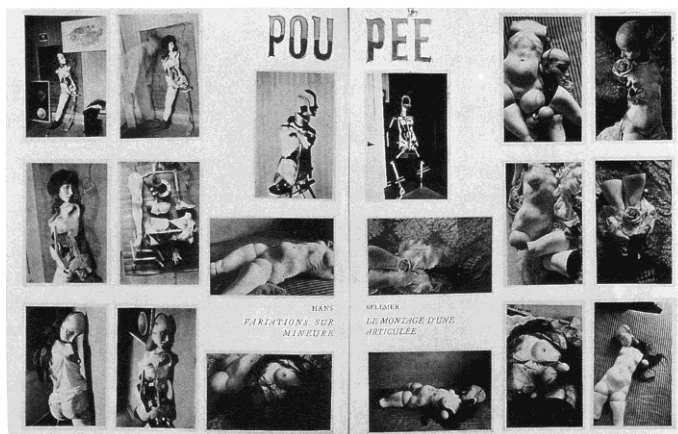


fig 4.10 Hans Bellmer. *Puppée: Variation sur le montage d'une mineure articulée*. 1934.

Bellmer constructed his first doll in 1933 and published a series of photographs in Albert Skira's surrealist-oriented journal, *Minotaure*, on 5<sup>th</sup> December 1934 under the title 'Puppée: Variation sur le montage d'une mineure articulée' [Doll: Variations on the Assemblage of an Articulated Minor].

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<sup>195</sup> Lebbeus Woods testifies to the power of radical architectural ideas: 'The only thing that is radical is space we don't know how to inhabit. This means space where we have to invent the ways to act and to live.' Quote taken from Alison 2006, 7.

<sup>196</sup> Mical 2005, 5.

<sup>197</sup> Banham 1984 [1969], 146.

For Bellmer himself, the ideal body was artificial and manipulable.<sup>198</sup> In an unpublished script of 1946 Bellmer wrote about constructing the human body as it were an anagram: 'I am talking about the possibilities of decomposing and then recomposing the body and its limbs "against nature."<sup>199</sup> 'The body resembles a sentence,' wrote Bellmer, 'that seems to invite us to dismantle it into its component letters, so that its true meanings may be revealed ever anew through an endless stream of anagrams'<sup>200</sup>. As Steven T. Brown explains in *Mechademia* 3, '[w]hat Bellmer was attempting to do with this doll experiments was to construct corporeal anagrams.'<sup>201</sup> Bellmer exclaims his motivation for constructing the dolls: 'I shall construct an artificial girl whose anatomy will make it possible to recreate physically the dizzy heights of passion and to do so to the extent of inventing new desires.'<sup>202</sup>

If there were an architecture seeking to 'invent new desires' in the image of Bellmer's poupée, then it could possibly be Frederick Kiesler's *Endless House* (1947-1961). As alternative vision to the white-wash, de-historized architecture Kiesler developed through constellations of drawings, models and writings the *Endless House*, as proposal for conjoining and reuniting 'individual and social necessities and desires with human origins ...'<sup>203</sup>. Stephen Philips explains in his essay 'Introjection and Projection: Frederick Kiesler and his Dream Machine,' 'Kiesler created a machine for dreaming, as a living organism that can be inhabited and engaged by the body.'<sup>204</sup> Thus, it can be said that for both, Bellmer and Kiesler, the creative act was a mechanism for inventing new desires. By transferring physical qualities of the organic body and psychic qualities of human being onto an artificial medium they could condition not only new desires but furthermore propagate new relations between man and his creations. Both men were welcome by the

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<sup>198</sup> Bellmer's obsession with dolls was jointly inspired by his obsession with his teenage cousin Ursula and by Offenbach's opera *The Tales of Hoffmann*, which features a mechanical doll. For further details on Bellmer's obsession with dolls see 'Fetishism and the First Doll' in Taylor 2000.

<sup>199</sup> Quoted in Agnès de la Beaumelle, 'Hans Bellmer: The Stakes at Play in Drawing *Les Jeux de la poupée*,' in Senff and Spira 2006, 35.

<sup>200</sup> Bellmer, Hans, 'Little Anatomy of the Physical Unconscious, or the Anatomy of the Image,' in Bellmer 2005 [1934], 133.

<sup>201</sup> Brown 2008, 236.

<sup>202</sup> Explanation given in the catalogue to the major retrospective exhibition at the Centre National d'Art Contemporain in 1971 in Paris; quoted in Webb and Short 1985, 29.

<sup>203</sup> Krzysztof Fijalkowski in catalogue for exhibition *The Surreal House*, 2010, 318.

surrealist as creative forces in a struggle against the predominant ‘misconceptions about technology.’<sup>205</sup> Bellmer, when he visited Paris in 1935<sup>206</sup> and Kiesler on his early collaborations with Marcel Duchamp in New York.<sup>207</sup> And indeed, the contrast highlighted by Thomas Mical’s fantasy of Bellmer’s poupée inhabiting a modernist building is instantly blurred by fantasizing the poupée in the interiors of the *Endless House*.

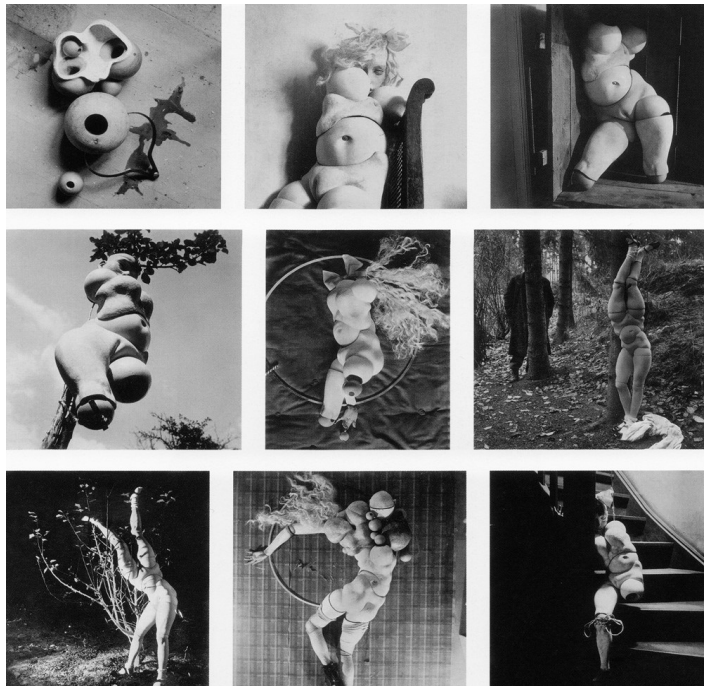


fig 4.11 Hans Bellmer. *Les jeux de la Poupée*. 1938.



fig 4.12 Frederick Kiesler. *Endless House*. 1947-1961. Interior views.

<sup>204</sup> Philips 2005, 152.

<sup>205</sup> Hultén 1968, 160.

<sup>206</sup> By February 1935, following meetings with Henri Parisot, Paul Eluard, Robert Valancay and André Breton, Bellmer was included in a surrealist group exhibition at Galerie des Quatre Chemins (Taylor 2009, 201).

<sup>207</sup> Kiesler showed work in October 1942 in Peggy Guggenheim’s The Art of This Century gallery where Marcel Duchamp also exhibited and coincidentally at the same time stayed at Kiesler’s Greenwich Village apartment (Kachur 2001, 204).

This strange cohabitation brings together the strategies of two individuals who have operated on the fringes of the surrealist project, yet they created in their work what André Breton described as the ability of the surrealist object to produce ‘uninterrupted succession of *latencies*’ from the ‘*hidden real*’ to the ‘*total revolution of the object*.’<sup>208</sup> ‘[T]he irregular surrealist body of semiotic impulses, banished from the prismatic rationalist volumes of an industrialized world, returns as its uncanny guest.’<sup>209</sup> Its project is the potential destruction of the Cartesian/ Kantian language of intelligibility. Under the playful watch of the surrealists, ‘the body in architecture rediscovered its animal origins, evoking sexuality, perversion, excess, and uncontrollability ... [b]odies became like machines and vice versa.’<sup>210</sup>

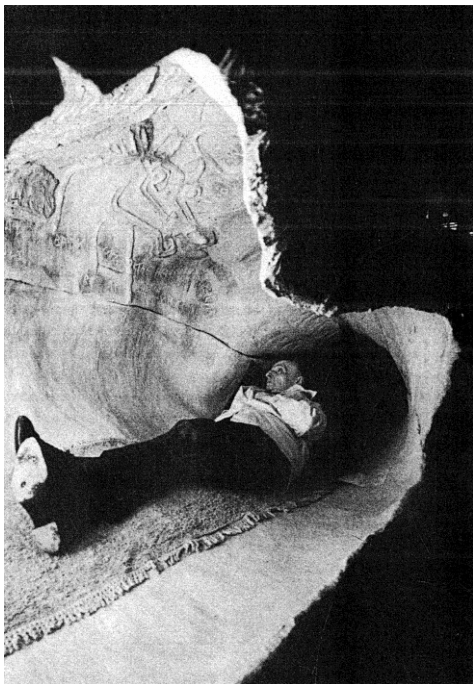


fig 4.13 Photograph of Frederick Kiesler inside *Bucephalus*. 1964.

Kiesler’s dream-machine architecture was synonymous with the constituent properties of the human body, a ‘living machine’ wrapping around the moving body and symbiotically linking up in support of its metabolism.<sup>211</sup> From a contemporary perspective, Greg Lynn

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<sup>208</sup> Breton 1965 [1936], 86.

<sup>209</sup> Mical 2005, 5.

<sup>210</sup> Bonnemaison 2009, 53.

<sup>211</sup> Kiesler 1939, 64+71.

judges Kiesler's unique interpretation of the centrality of the human body in the architectural project when he writes that, '[t]he primary importance of Kiesler today is that he ... broke with the classical humanist model of the human body and designed for a new type of inhabitant' embracing 'biomorphic forms both symbiotically and morphologically.'<sup>212</sup>

### **Biomorphic corporeality**

Kiesler's own physical identification with his architecture was manifested in photographs that reveal his intimate relation with the *Endless House*, his own body the biological machine around which the architecture is constructed.<sup>213</sup> The biomorphism of his own corporeality quite literally informed the biomorphism of his architecture. However, the idea that the human body can be exploited as a source of inspiration is a dominant thematic in the visual, sculptural and performative arts. As Johanna Malt notes in *Obscure Objects of Desire*, in surreal art

the body itself figures as object and as fetish, presented in fragmentary forms and the form this partial configurations take on are amongst the most familiar images of surrealism: the disembodied breast and feet in Magritte's *Philosophie dans le boudoir*, the dislocated mannequins of Hans Bellmer and of the Paris international Exhibition of 1938, the gloved hand, the photographed stocking model leg, still in its high-heeled shoe ... and the Story of the Eye.<sup>214</sup>

But in architecture, the human body is generally referenced as a whole; in particular, its physical presence and needs impose a layer of pragmatism onto the architectural project that is undeniable even in the visionary projects of Kiesler.

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<sup>212</sup> Lynn 2001, 69.

<sup>213</sup> Beatriz Colomina makes the observation that it is because of the physical frailty of his body towards the end of his life Kiesler 'always photographed his own body inside the body of the building ... as if the house became his surrogate body. See Colomina, Beatriz. 'The Medical Body in Modern Architecture' in Davidson 1997. pp 228-239. p 237.

<sup>214</sup> Malt 2004, 103.



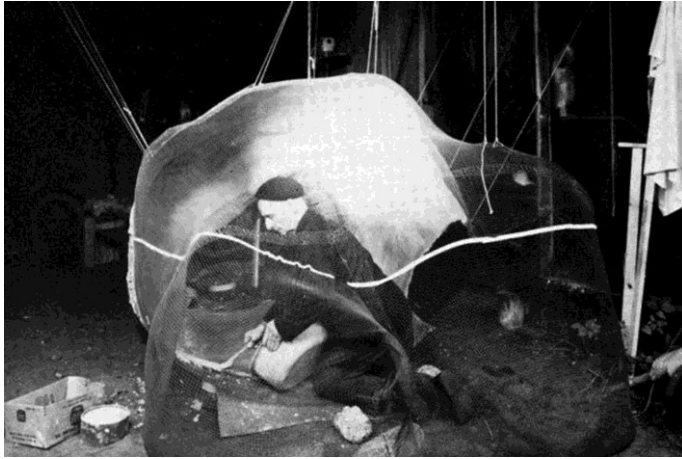


fig 4.14 Frederick Kiesler inside a model for the *Endless House*.

The body as central point of reference and the resulting anthropocentric conditioning of architecture is emphasized by Kiesler when he notes that the '[t]echnological environment is produced by human needs. Investigation of this crucial point cannot be based by a study of architecture but must be based on a study of the life processes of man.'<sup>215</sup>

In 1936 Kiesler was appointed associate professor at Columbia University School of Architecture where he established the *Laboratory for Design-Correlation* in 1937. Kiesler and his students 'advanced an interest in time and motion and developed a theory of Biotechnique as inspired by the work of Sir Patrick Geddes,'<sup>216</sup> which would form the basis for a series of articles published in the *Architectural Record* in the 1930s and would eventually provide Kiesler with the conceptual material for the much cited article *On Correalism and Biotechnique: a Definition and the New Approach to Building Design* (1939).<sup>217</sup> Their extensive observations of the human body in relation to its artificial realm relied on time-motion studies similar to those of Eadweard Muybridge and Etienne-Jules Marey. But in contrast to modernist architecture that, in allying with Fordist practices and Taylorist ideals, favoured the corrective transformation of the human body, Kiesler sought to develop 'a typology of organic architecture – a living machine – designed to *modulate* to man's motion in time counter to Le Corbusier's vision of the home as a machine for living.'<sup>218</sup> A decade later, Kiesler reinforced the theoretical foundations for his holistic programme for architecture in the *Manifeste du Corréalisme* (1949), where he stressed the

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<sup>215</sup> Frederick Kiesler TV interview/ Mac Andrew, 'Camera Three', CBS 1960, printed in Bogner 2003, 88.

<sup>216</sup> Phillips 2005, 145.

<sup>217</sup> Kiesler 1939.

idea of architecture as an integrative system of ecology, social structures and biomorphism.<sup>219</sup> Kiesler's attempt to infuse architectural forms with biomorphic corporeality for many of his fellows was the embodiment of surrealist architecture. Surrealist artist Hans Arp has noted on Kiesler's *Egg House*, that 'in these spheroid egg-shaped structures, a human being can now take shelter and live as in his mother's womb.'<sup>220</sup> Certainly, Kiesler's revolutionary architectural anatomies inspired the imagination of a mysterious architecture, in as much as the *Endless House* reflected an architect's desire to symbiotically position architecture between the human body and the natural environment.

Architecture might not have been the most frugal field of expression for surrealists but some exponents certainly entertained the idea of intimate relations between body and architecture. As art historian Haim N. Finkelstein observes, 'to be enclosed in an irrationally conceived object-house (interior), surrounded by "surrealist" objects – this seems to be, by implication, the uppermost ideal of the surrealist dream architecture.'<sup>221</sup> Kiesler's visions, despite their ignorance of technological developments, are today seen as some of the most radical efforts to invent new ways of inhabiting architecture, by reconsidering the role of architecture but foremost placing all that is human at the centre of all considerations. Such an anthropocentric approach highlights the possibilities of exchange between the bodies in which we grow and the bodies that we build. Surrealist efforts to re-articulate the relation to the object in relation to subject—the Bretonian thematic of the *crise d'objet* vis-à-vis the self—stimulated architectural thought to address the body in relation to the enclosure. In the then fashionable combination of organic and psychoanalytical method, qualities of partial biological bodies were projected onto architecture and resulted in 'inauterine' architecture equipped with the imagery of the feminine and architectural vision of *biomorph corporalities*. Thus, the search for symbiotic relations of human bodies with their architecture became the search for an anthropological dictum that began as a surreal dream of architecture and has subsequently continued to evolve with the technologization of the architectural environment.

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<sup>218</sup> Kiesler 1939, 64+71.

<sup>219</sup> Kiesler 1949.

<sup>220</sup> Arp in Vesely 1978, 87-95.

<sup>221</sup> Finkelstein 1978, 114.

## Shifted anthropocentrism

Surrealist architecture, such as Kiesler's dream-machine *The Endless House* or Matta's anthropomorphic architecture composed of partial bodies, expressed, though never realized in full scale, architecture in symbiotic relation to human beings. These projects constituted not only an effort to challenge architecture's dictum for order and efficiency, but aimed to productively entangle the order of the human being (excess, sensuality, perversion) with the order of the machine (productivity, economy, control). As classical ideals have been challenged by scientific, industrial and social revolutions, anthropocentrism – in many respects a universal value of architecture – has been revolutionised. Comparable to the application of classical ideals of symmetry and proportion of the human body to architecture, surrealist ideas, in a sense, provoked a deeply anthropocentric contemplation of architectural space.<sup>222</sup> Technological, scientific and social developments in the twentieth century have introduced a new dimension to the anthropocentric mandate of architecture. Peter Eisenman claims in his much quoted text 'The End of the Classical' (1984) that 'modernist architecture was stripped of its 'anthropomorphic motifs' so that it could offer a 'simulation of efficiency based on scientific reason and technical positivism.' The age of modernity and its constituent but predominantly antagonistic artistic forms of expression, modernism and surrealism, finally overthrew the classical foundation of architecture. But despite challenging classical values these developments have also offered the opportunity to relate architecture to the human being that co-exists with a technologized environment. The machine metaphor of modernism has not only severed the ties of human labour and the object (which has subsequently become a product), but has furthermore emancipated human sensuality from the body in order to entrust it to the artificial. The body is no longer just symbolized

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<sup>222</sup> Vitruvius compared the human body directly to the body of a building (*De Architectura*, Book III (On Symmetry: in Temples and in the Human Body). Since then the complex phenomenon of corporeality and how it is reflected in architecture has had a privileged position in European culture (Vesely 2002, 29). According to Wittkower, in the West, discussions of architectural anthropomorphism go back to Vitruvius, Alberti, Bramante, Leonardo, Palladio and Michelangelo (Wittkower 1967, 3-14; 101ff). In a letter of about 1560 Michelangelo wrote that 'there is no question but that architectural members reflect the members of man and that those who do not know the human body cannot be good architects (quoted in Wittkower 1967, 101 ftn 2; in Milanesi. 1875. *Le lettere di Michelangelo Buonaroti*. Florence. p554.). Michelangelo's instructional thesis that 'architectural members reflect the members of man' might be attributed to classical ideals of their age. But can it be completely dismissed? Can architects ignore the central agency of human corporeality in architecture?

geometrically but reflected as function and performance in technological systems. In short, architecture's ability to assimilate corporeal capacities has changed.<sup>223</sup> These strategies allow the perception of new reciprocities between the human body, machines and architecture.

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<sup>223</sup> See Hight 2008 for an account of how body, anthropomorphism and proportion have been affected by the shift to cybernetic technologies and digital design.

### s3 | Pneumatic bodies

Austrian Pneumatics – Pneumatic anthropocentrism – Inflatables and responsive architecture – Pneumatic body-machine hybrids

Only a couple of years after Burroughs published his novel *The Soft Machine* (1961) and at roughly the same time as Reyner Banham demonstrated in *The Architecture of the Well-Tempered Environment* (1969) the inextricable entanglement of technology and architecture, visionary tendencies in architecture emerged experimenting with more tangible and physically reciprocating notions of exchange between the human body and its artificial architectural extensions. The freedom and immediacy of human action and sensuality informed ambitions for spatial design. Art forms such as installations became the medium for experimenting with social aspects of architecture. An emerging technology for architectural experimentation was pneumatics, which seemed to suit the utopian spirit of the moment.<sup>224</sup> Architects, such as Antoine Stinco or J.P. Jungmann who devised an experimental pneumatic dwelling ‘in which *everything* is inflatable – structure, membrane, flooring, partitioning, furniture and equipment’<sup>225</sup> or Jose Miguel de Prada Poole who devised the dynamically transformable structure *La Casa Jonás* (1968)<sup>226</sup> took the Inflatable movement into highly speculative realms.<sup>227</sup>

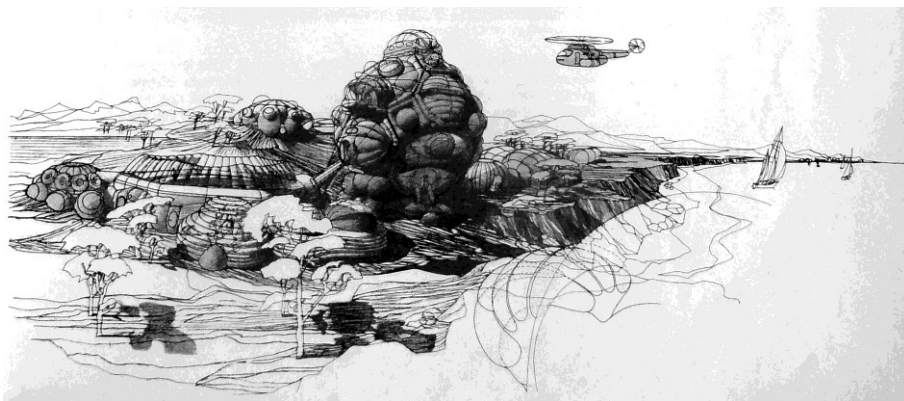


fig 4.15 J.P. Jungmann. *Dyodon*. 1968. Perspective view of an experimental pneumatic dwelling.

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<sup>224</sup> Conolly et al. 1968.

<sup>225</sup> Jungmann in Conolly 1968, p276-77 [italics in original].

<sup>226</sup> <http://cyberneticzoo.com/?p=6824>, accessed 2012/11/12.

<sup>227</sup> Dessauce 1999; Topham 2002.

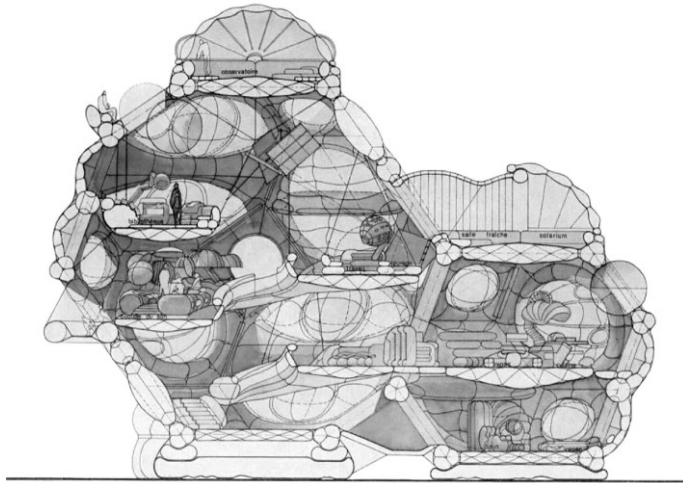


fig 4.16 Section of Jungmann's pneumatic dwelling.

'An experimental pneumatic dwelling in which everything is inflatable – structure, membrane, flooring, partitioning, furniture and equipment. It is intended to provide a complete experience of the pneumatic-way-of-life.'<sup>228</sup> Its structure is made up of transparent, translucent or opaque panels. The panels are filled with 'air, water, coloured gas, helium and even earth.'<sup>229</sup> *Dyodon* is Jungmann's diploma project. Named after the type of fish that puffs up when threatened, the project is 'foremost guided by graphic delectation and technical feasibility.'<sup>230</sup>



fig 4.17 Jose Miguel de Prada Poole. *La Casa Jonás*. 1968.

Built in the School of Architecture of Madrid the project goes beyond the metaphors of adaption by providing a smart structure that can respond to stimulus through movements of distributed but connecting pneumatic structures.

Architectural historian Marc Dessauce traces in his book *The Inflatable Moment* a link between the nature of pneumatic structures and the grassroots protests of 1968: 'Pneumatics and revolution agree well ... they animate and transport us on the promise of

<sup>228</sup> Jungmann in Conolly et al. 1968. pp.276-277, p. 276.

<sup>229</sup> Dessauce 1999, 89.

<sup>230</sup> Dessauce 1999, 89.

an imminent passage into a perfect future.<sup>231</sup> In his analysis of the pneumatic movement Marcos Cruz speaks of an ‘evocative pneumatism’ emerging from the proximity between bodies and pneumatic buildings which are ‘unimpeded by the material restrictions’ of inert conceptions of architecture.<sup>232</sup>

A discussion of early precedents of architectural pneumatics helps contextualise the relevance of pneumatics in my own work. The morphological freedom of pneumatic form and its inherent transformational potential are appealing, not only when seeking to inform architecture with notions of the dynamic and transformational but also when conceiving of architecture as a compliant environment that is ‘weaker’ in material terms than human bodies. In this sense, soft machines are informed by pneumatic conditions – the relation between passive softness and activity being dynamically and simultaneously shaped by material limits as well as external influences. The utopian pneumatic projects and experiments, discussed in this section as well as in chapter 6 [c6. s3 Pneumorphic precursors in architecture: Frei Otto’s pneumatic motion systems and soft systems], are inspirational leitmotifs for the design of my soft machines. As their architectural materiality is weaker and softer than the one they relate to, these projects offer the imagination of softer and more compliant relations between human beings and architecture.

## **Austrian Pneumatics**

For the Austrian architectural groups Haus-Rucker-Co<sup>233</sup> and Coop Himmelb(l)au,<sup>234</sup> the experience of space could no longer be defined by stiff material enclosures. In their poem ‘Die härtere Architektur [The harder Architecture]’ – criticizing the socially disastrous outcome of the Reagan/Thatcher eighties – Coop Himmelb(l)au affirmed: ‘The harder the times, the harder the architecture.’<sup>235</sup> One of the characteristics of Haus-Rucker-Co and Coop Himmelb(l)au’s architectural installations and machines at that time has been

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<sup>231</sup> Dessauce 1999, 13.

<sup>232</sup> Cruz 2014, 109.

<sup>233</sup> Haus-Rucker-Co, literally translated into English means House-Pushing-Co.

<sup>234</sup> Coop Himmelb(l)au was founded in 1968 by Wolf D. Prix, Michael Holzer, Helmut Swiczinsky in Vienna.

<sup>235</sup> Coop Himmelb(l)au 1980 in Porsch 2009. Original German quote: ‘Je härter die Zeiten, umso härter die Architektur.’

the use of soft pneumatic plastic skins: a medium that anticipated direct contact with the human body and gave the work itself a body-like behaviour and materiality, advocating physical engagement and exchange. Haus-Rucker-Co and Coop Himmelb(l)au's installations were concerned with the dynamisation of space, information theory and sociodynamics.<sup>236</sup> They were part of what Peter Cook would call the 'Austrian Phenomenon',<sup>237</sup> a movement that never articulated itself as such, but nevertheless had a wide ranging influence on architecture in Austria and beyond.<sup>238</sup> Günther Feuerstein noted that 'even though the movement of the sixties and seventies behaved itself as revolutionary, it still stood on traditional ground.'<sup>239</sup> Next to historical continuity there was lively exchange with many contemporary figures and influences.<sup>240</sup> They were:

- a) Frederick Kiesler, the Viennese universal genius, who migrated from Vienna to New York in 1926. His *Endless House* project was seen as a milestone in the search for a new architectural language,
- b) happenings and actions ['Aktionen,' in German] as they were the chosen artistic expression of the time. Wiener Aktionismus [Viennese Actionism] with its protagonists Otto Mühl (*Fest des psycho-physischen Naturalismus*, 1963), Hermann Nitsch (*Orgien Mysterien Theater*, from 1962 – present), Rudolf Schwarzkogler (*3rd Action*, 1965) and Günter Brus (*Zerreißprobe*, 1970) probed the boundaries of taste and thresholds of physical pain by most revolting physical experiments,<sup>241</sup> and
- c) influences from outside Austria, most notably the London group Archigram<sup>242</sup> which included Peter Cook with whom the Viennese architects had extensive contact. Cook

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<sup>236</sup> Prader and Fehringlerl [1967] in Porsch 2009, 123.

<sup>237</sup> Cook 1970, 71.

<sup>238</sup> The socio-political, cultural, architectural and artistic output is documented in Porsch 2009. There have been many other influential figures, most notably Hans Hollein, Walter Pichler, Max Peintner and Günter Feuerstein.

<sup>239</sup> Feuerstein 2004, 62.

<sup>240</sup> Feuerstein himself has been appointed with a teaching position at Karl Schwanzer's Institute for Design at the Technical University (TU) of Vienna in 1963, where he became an influential teacher of many of the protagonists of the Viennese architectural scene, including Ortner and Prix. From 1965 the TU Vienna became a trouble spot, with Feuerstein as central figure. He had recruited a large number of students around him 'whose interest went beyond obtaining a diploma' (Prader and Fehringlerl [1967] in Porsch 2009, 121).

<sup>241</sup> See *Out of Actions. Actionism, Body Art & Performance 1949-1979*, exhibition catalogue (Vienna-Stuttgart: MAK/Cantz, 1998).

<sup>242</sup> 'Archigram was an avant-garde architectural group formed in the 1960s - based at the Architectural Association, London - that was futurist, anti-heroic and pro-consumerist, drawing inspiration from technology in order to create a new reality that was solely expressed through hypothetical projects. The



noted two characteristics that distinguish the London from the Viennese architects: the trend to action and the subtle, virtuous drawing.<sup>243</sup>

Further to Cook's observation, groups such as Haus-Rucker-Co and Coop Himmelb(l)au focussed at that time on projects as installations, rather than purely drawn work. Consequently, the distinctive element of the Austrian works was 'that they could be realised and exhibited in temporary installations, so that, in contrast to the British concepts, they could actually be 'experienced,' as Bart Lootsma observes in his article 'Towards a Second Nature.'<sup>244</sup> Lootsma point out that the development of the concept of dwelling 'towards a capsule or a technically equipped suit, is unmistakably inspired by the rapid developments that were taking place in the field of space travel at that time.'<sup>245</sup> As the human body was prostheticized with increasingly sophisticated equipment, technology became the agent for projecting human capacities into the realm of architecture. Whilst many of these developments were a direct result of cold war research programmes, 'they were all perceived to extend the capabilities of mankind, and as a result technology was seen as a form of social emancipation which was to be embraced.'<sup>246</sup> The technology euphoria of the 1960s seemed to be capable of granting architecture the symbiotic alliance with the human body that the surrealists (Tzara, Matta, Kiesler) of the 1930s so much desired.

### *Haus-Rucker-Co*

Haus-Rucker-Co was founded by architects Laurids Ortner and Günter 'Zamp' Kelp, together with the painter Klaus Pinter as an experimental architectural team in 1967. The group invented 'a kind of funny architecture for the leisure society', 'psychedelic chairs'

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main members of the group were Peter Cook, Warren Chalk, Ron Herron, Dennis Crompton, Michael Webb and David Green' (Sadler 2005, 161).

<sup>243</sup> Feuerstein 2004, 76.

<sup>244</sup> Lootsma 'Towards a Second Nature' (1996) in Porsch 2009, 206-208. One notable exception is Archigram's *Cushicle Model*, 1968.

<sup>245</sup> Lootsma 1996 in Porsch 2009, 208.

<sup>246</sup> Holding 2000, 20.

and ‘self-folding machinery,’<sup>247</sup> ‘elegant pneumatic structures inside which they include ideas of life support machinery.’<sup>248</sup>



fig 4.18 Haus-Rucker-Co. *Flyhead, Viewatomiser and Drizzler*. 1968.  
Environmental Transformer helmets.



fig 4.19 Haus-Rucker-Co. *Mind Expander I*. 1967.

‘The seat shell fixes two persons in a certain position. The lower seat allows one person to sit with their legs slightly open. The thigh of their right leg rests against a step forming the transition to a second seat area that is higher by the thickness of a thigh. A helmet-like balloon that is connected with the seat can be tilted over the heads of the two people seated. Their heads thus are enclosed by a narrow cylindrical space that is covered by a glass-clear plastic dome above which a transparent balloon hovers. A series of lines and stamped-out shapes made of reflective foil are placed on both the dome and the surface of the balloon in such a way that, depending on whether you concentrate on the level closer or further away from you, the elements constantly overlay each other to form new pattern.’<sup>249</sup> ‘However distinctive the form of this appliance may be, the effect is nevertheless to focus exclusively on expanding visual perception.’<sup>250</sup>

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<sup>247</sup> Prader and Fehringler [1967] in Porsch 2009, 121.

<sup>248</sup> Cook 1970, 75.

<sup>249</sup> Ortner 2000, 182.

<sup>250</sup> Ortner 2000, 139.

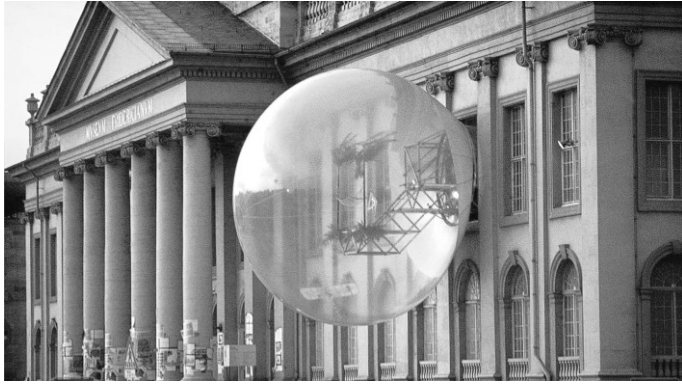


fig 4.20 Haus-Rucker-Co. *Oase Nr. 7*. Installed at documenta 5 in Kassel. 1972.

*Oase Nr. 7* was a transparent sphere with a diameter of 8m installed in front of the main facade of the Fridericianum in Kassel. 'From the interior of the building a walkway made of standard steel tubing projected through the window. On it, set at some distance from the external facade, a ring made of steel pipe was mounted. Externally this ring carried the PVC foil shell of the sphere which was inflated by an air blower, while inside it formed the connecting element for a short tunnel made of the same material which could be closed at both ends with zips thus functioning as air lock. The part of the steel construction projecting out the window extended at an angle downwards into the centre of the space within the sphere. Here stood two palm trees with plastic leaves and trunks made of brass pipe with a hammock stretched between them.'<sup>251</sup> The project was re-created for the 2008 London Victoria & Albert museum exhibition 'Cold War Modern: Design 1945-1970.'



fig 4.21 Haus-Rucker-Co. *Ballon für Zwei* [Balloon for Two]. 1967.

'On the 21st of October 1967 at 2 o'clock in the afternoon, a large, unshaped and crinkled plastic skin moves through the window of the first floor of a house at Apollogasse 3 in Vienna. Having passed through the window, the structure unfolds in the public space outside and becomes a spherical balloon of 3.5m diameter.'<sup>252</sup> The transparent plastic skin of the installation unfolds with the use of an inverted vacuum cleaner. After approximately 15 minutes, the balloon is deflated and retracts into the building in order to repeat the sequence at every full hour, until 8 o'clock in the evening. This process is the dynamic creation of

<sup>251</sup> Ortner 2000, 186.

<sup>252</sup> Haus-Rucker-Co, 1984, p.72, original German, transl. by author.

a temporary 'dwelling sphere', allowing a man and a woman to pass through the threshold from the interior of the building to the exterior into the public domain.



fig 4.22 Haus-Rucker-Co. *Gelbes Herz* [Yellow Heart]. 1968.

'Through an air lock made up of three air rings one arrived onto a transparent plastic couch. Just big enough for two people it projected into the centre of a round space built-up of soft air chambers. If one lay here one could perceive how the air-filled cushions, which almost touched one with their swelling sides gradually withdrew and the surrounding space seemed to grow, and how they finally formed a translucent ball and then began to flow outwards again in a soft counter-movement. A grid of large dots on the inner and outer surfaces of the air shell transformed in rhythmic waves from milky patches to a clear pattern. The space pulsed at intervals.'<sup>253</sup>

### *Coop Himmelb(l)au*

The motto of the building cooperative Coop Himmelb(l)au was the 'liberation of architecture from itself' and their projects, conceived as living apparatus with fold-out platforms and balloons and globules of PVC 'presupposed highly complex technology ... that has not fully arrived yet and therefore isn't on the university curriculum anywhere.'<sup>254</sup> The group's universal motto was 'an architecture that is as variable as a cloud'<sup>255</sup> and their mechanical and pneumatic apparatuses, models and projects sought to express this agenda. As Anthony Vidler notes, one of the first projects, 'the "Michelin Man" pneumatic Villa Rosa of 1968' explored 'the possibilities of technology as a "natural" extension of the body.'<sup>256</sup>

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<sup>253</sup> Ortner 2000, 85.

<sup>254</sup> Prader and Fehringerl [1967] in Porsch 2009, 123.

<sup>255</sup> Coop Himmelb(l)au 2007, 54.

<sup>256</sup> Vidler 2000, 188.

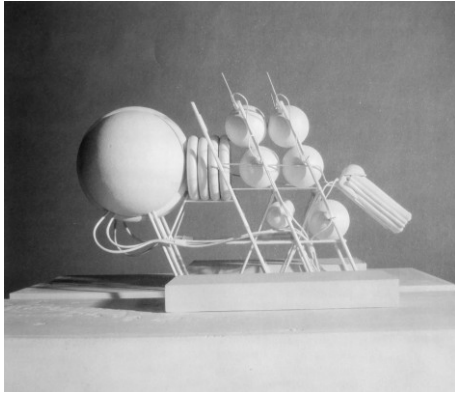


fig 4.23 Coop Himmelb(l)au. *Villa Rosa*. 1968.

The pneumatic construction of the *Villa Rosa* project permits changes in volume due to a new building element: air. New forms supported through projections of colour, sound, and fragrance, are influencing the experience of space. The pneumatic, transformable balloons vary in size. The whole construction can be transported in a suitcase. 'From a helmet-shaped suitcase, one can inflate an air-conditioned shell, complete with bed.'<sup>257</sup>

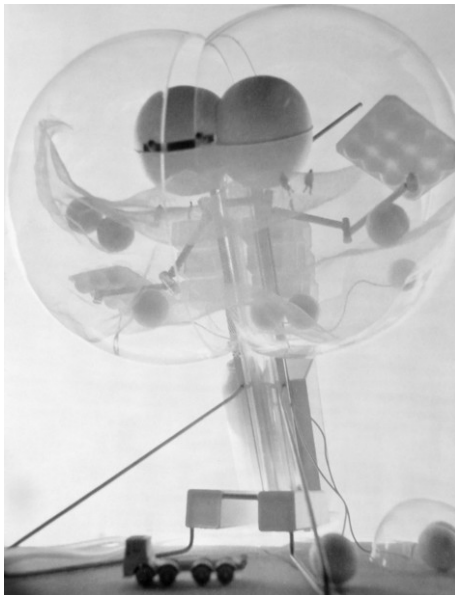


fig 4.24 Coop Himmelb(l)au. *Wolke* [The Cloud]. 1968.

'The cloud is an organism for living. The structure is mobile, the space can be modified. The building materials are air and dynamics. (Technique is a mere means to an end, but not an end in itself. Architecture is content, not shell).'<sup>258</sup>

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<sup>257</sup> Coop Himmelb(l)au 2007, 54.

<sup>258</sup> Coop Himmelb(l)au 2007, 58.

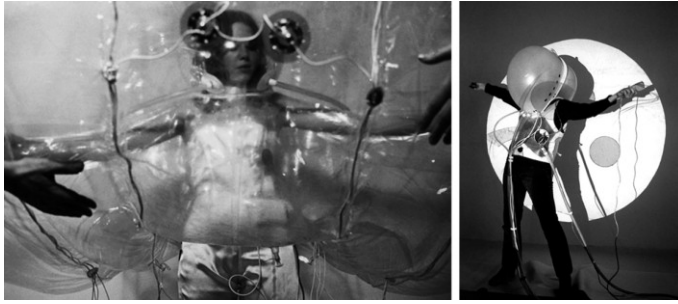


fig 4.25 Coop Himmelb(l)au. *Herz Stadt – der weisse Anzug* [Heart City – the white suit]. 1969.

‘The cold medium of TV is getting hot. The audiovisual information that appears on and in the projection helmet is supported by smells. And the pneumatic vest presents tactile information.’<sup>259</sup>

### Pneumatic anthropocentrism

The early works of Haus-Rucker-Co and Coop Himmelb(l)au demonstrated a spirit for questioning architecture’s essence and its social reality. ‘How should new forms of society be defined through form itself?’ asks Laurids Ortner in ‘You got LIVE if you want it.’<sup>260</sup> As Dietmar Steiner would observe in his article on ‘Austria’s Phenomenon’ in 1976,

[s]pace no longer defines itself through its material existence, but rather the intensity of media employed determines the level of experience. The exuberant freedom of sensuality independent of constructed space led to domicells, aggregates and simulators that painted the future a shade of ‘vanilla yellow’ (Haus-Rucker-Co) and freed the way to inner space.<sup>261</sup>

Coop Himmelb(l)au state in an untitled text in 1968, ‘Our architecture does not have a physical ground plan, but a psychological one. There are no more walls. Our rooms are pulsating balloons. Our heartbeat becomes space, our face is the façade of a house.’<sup>262</sup> The argument sets up a direct analogy between the house and the body and is symptomatic of the dominant anthropocentric agenda of these architectural projects. For instance, inherent anthropo/logic/centric/morphic analogies (*Yellow Heart* (1968), *Mind Expander* (1967), *Heart City* (1969)) expressed an intentional parallelisation of body and building. But

<sup>259</sup> Coop Himmelb(l)au 2007, 64.

<sup>260</sup> Ortner 2009 [1999], 937.

<sup>261</sup> Steiner 2009 [1976], 172).

rather than projecting the whole body, only fragments are projected onto architecture. The architectural installation (as a model for a new kind of architecture) has become a second sort of body, extending and incorporating corporeal powers by assimilation of the body. In the late 1960s, these young architecture groups have materialised the surrealist visions of Tzara and Matta's 'intrauterine' spaces or Kiesler's allusion to 'the house [as] the skin of the human body.' By using all means at their disposal, from mechanics, electronics and pneumatics to psychedelia, Haus-Rucker-Co and Coop Himmelb(l)au experimented with the extra-corporeal potential of architecture. As the premise for these projects was 'action', these projects triggered a physical engagement of body, architecture and machine (pneumatics, etc.), thus installing architecture as an integral and active agent of social relations. Architecture truly had a body.

### **Inflatables and responsive architecture**

Phrases such as Marshall McLuhan's 'extension of our bodies and senses' became leitmotifs for a new phase of experimental architecture.<sup>263</sup> Pneumatics – even though the basic patents on air-supported buildings go back to F. W. Lancaster in 1917 – began to appeal to architects because of their capacity to change almost as quickly as the taste of their inhabitants. On this notion Reyner Banham observed in his article 'Monumental Windbags' (1968): 'What is new is the confluence between changing taste and advances in plastic technology. The taste that has been turned off by the regular rectangular format of official modern architecture and Bauhaus-revival ... is turned right on by the apparent do-it-yourself inflatable technology.'<sup>264</sup> The dynamic and transformational potential of pneumatic structures, combined with the emerging convergence of mechanics with computational technologies [s2.s2 Convergence of computation and machine] enabled architects to experiment with a new sort of anthropocentric modalities – responsiveness and interaction facilitated by pneumatics.

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<sup>262</sup> Coop Himmelblau in Porsch2009 [1968], 16.

<sup>263</sup> McLuhan 1964, 252.

<sup>264</sup> Banham 1968. Banham's writing was also used as a preface to the first major survey of pneumatic structures, the 1968 'Pneuwold' *Architectural Design* issue.

### *Mark Fisher's transformable pneumatics*

In 1968 the concert stage designer Mark Fisher, studying under Peter Cook at the Architectural Association, undertook a series of pneumatic experiments investigating how to create environments that could respond in real time to users' changing physical requirements. Fisher's fascination with the new pneumatic technologies is manifest in his *Automat* (1968) project, which he carried out in collaboration with fellow student David Harrison [c2.s1 Devices].<sup>265</sup> The low-pressure pneumatic structure could selectively expand or contract in response to user's requirements. Fisher took his fascination with transformable pneumatic structures further by developing the *Dynamat* (1969-72) together with fellow student and co-editor of 'Pneu World' Simon Conolly. *Dynamat* was a multi-cell pneumatic structure that could dynamically change its shape to pre-programmed sequences.<sup>266</sup> This type of arrangement will be discussed in more detail and in context with similar work in chapter 6 [s3. Morphodynamic transformations and space-making].

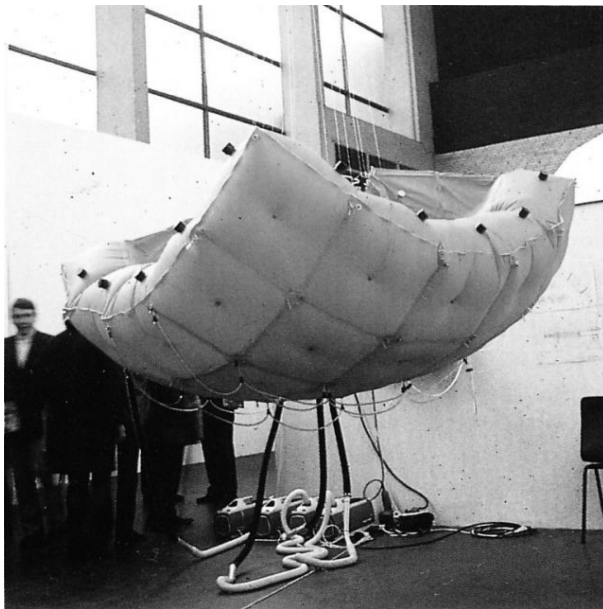


fig 4.26 Mark Fisher and Simon Conolly. *Dynamat*. 1969-71.  
Full-scale prototype panel with inverted vacuum-cleaners for air supply.

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<sup>265</sup> Fisher's fascination with pneumatics can be traced back to his first sightings of an anthropomorphic inflatable *Mother of the Arts* in 1966. It was an inflatable woman designed by fellow Architectural Association students for the annual Lord Mayor's procession. It was based on Jean Tinguely's *She*, a long, hollow reclining woman whose vagina was an entrance. During the procession, the designers of *Mother of the Arts* wielded coloured marker pens on the inner surface of the clear polythene blow-up. <http://cyberneticzoo.com/?p=6913>, accessed 02/12/2012

<sup>266</sup> Holding 2000, 22 and Bubner [IL 12] 1975, 20.



### *Negroponte and Wellesley-Miller's inflatable soft machines*

In his book *Soft Architecture Machine* (1975), Negroponte observed that the computational revolution provided the opportunity to overcome the socially restrictive notion of industrialisation which 'brought sameness through repetition' by developing 'custom-made, personalized artefacts'.<sup>267</sup> Negroponte referred to these technologies as soft machines, gesturing towards custom-made environments to be more reflective of personal needs, 'implemented with techniques of industrialization, augmented by computing systems'.<sup>268</sup> Negroponte maintained that '[s]oft materials, such as inflatable plastics, are presently the most natural material for responsive architecture'.<sup>269</sup> Research into pneumatically transformable cellular structures was undertaken by Sean R. Wellesley-Miller, then based at MIT's Robotics Lab<sup>270</sup> [c6. s3 Third generation pneumatic structures].

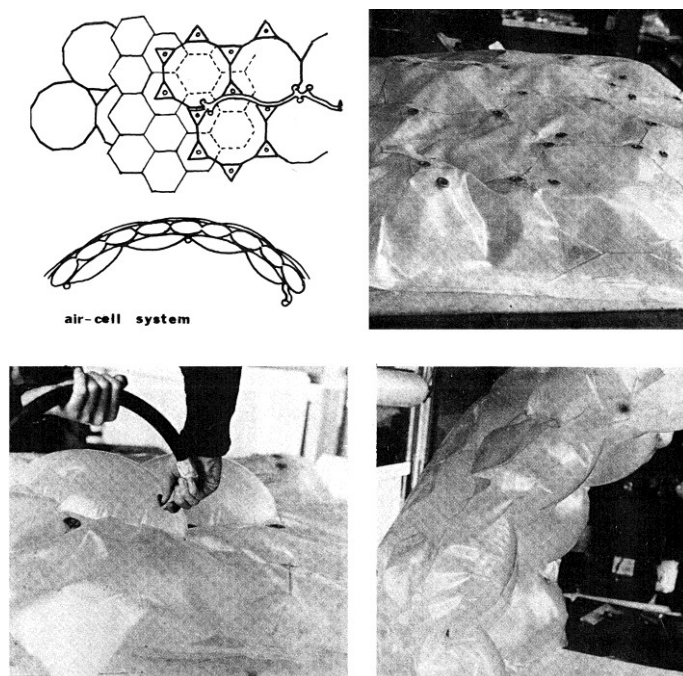


fig 4.27 Wellesley-Miller. A responsive dome constructed as pneumatic cellular machine. 1968. The cellular dome can be increased or decreased in size through pneumatics.

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<sup>267</sup> Negroponte 1975, 145.

<sup>268</sup> Negroponte 1975, 145.

<sup>269</sup> Negroponte 1975, 147.

<sup>270</sup> Wellesley-Miller, in Groot (ed.) 1972, Section 3.8. SWM 1-23.

Negroponte himself did not pursue physical experimentation with ‘softs’ but refers to research undertaken in the area of inflatable plastics.<sup>271</sup> Although he voices reservations about taking the term ‘soft’ too literally by ‘brutally transposing it from a computational paradigm to a building technology,’ Negroponte believes that ‘softs’ are an important vehicle to responsiveness.<sup>272</sup> Negroponte suggests by discussing a cellular pneumatics projects constructed by Wellesley-Miller that by fitting these structures with pressure-sensing devices it would be possible to have ‘the structure respond locally to body movements and interactions.’<sup>273</sup> Such ideas point towards possibilities of physically constructing meaningful anthropological relations between humans and soft architectural machines [c5. s2 Omar Khan’s soft kinetic gymnastics].

### **Pneumatic body-machine hybrids**

Ideas sketched out by Negroponte and Fisher in the 1970s have been experimented with in a contemporary context at Kas Oosterhuis’ Hyperbody Research Group at Delft University.<sup>274</sup> Projects such as *E-motive House* (2002), *NSA Muscle* (2003) and *MuscleBody* (2005) fuse the pneumatic ideas of the 1960s and 1970s with computer-controlled, interactive technologies that emerged in the 1990s.<sup>275</sup> Oosterhuis draws parallels to Negroponte’s *Soft Architecture Machines* when he characterizes the *NSA Muscle* project as a ‘paradigm of programming soft design machines.’<sup>276</sup> Pointing to an architecture that not only uses the digital rhetoric of fluidity, adaptability and softness but actually embodies it, *NSA Muscle* consists of a soft, inflated envelope festooned in a series of artificial muscles that are computer-controlled and pneumatically activated.<sup>277</sup> Oosterhuis notes that the project is a critique as well as a continuation of Ron Herron’s 1964 Archigram project

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<sup>271</sup> Negroponte 1975, 145-151. For research mentioned see Allen 1974, Schnarsky 1971, Wellesley-Miller 1972, Rusch 1972.

<sup>272</sup> Negroponte 1975, 147.

<sup>273</sup> Negroponte 1975, 149.

<sup>274</sup> The Hyperbody Research Group explores the architectural potential of programmable and interactive architectural environments by developing software and physical prototypes. The ultimate goal is to develop architecture that reconfigures itself in real time in response to user requests and proactively engages in the communication and reconfiguration progress (it is also connected to the internet).

<sup>275</sup> Salter 2010, 101.

<sup>276</sup> See Oosterhuis 2004, p 94-96. See also Beigl, Flachbart, Weibel, 2005, p 94 for description of method.

<sup>277</sup> Oosterhuis 2011, 118.

*Walking Cities* by stating that ‘programmable buildings can reconfigure themselves mentally and physically, probably without considering to completely displace themselves.’<sup>278</sup> The *NSA Muscle* architecture machine is a ‘prototype for an environment that is slightly out of control.’<sup>279</sup>



fig 4.28 Kas Oosterhuis and Hyperbody Research Group. *NSA Muscle*. 2003.

The *NSA Muscle* prototype has been shown at the 2003 *Non-Standard Architectures* exhibition at the Centre Pompidou. The structure could change its shape based on sensor orchestration of individual muscle strands ... due to the proximity of visitors or be steered from a more traditional screen-based interface (Salter 2012, 101).

Referring to architecture, in his text ‘Smart Skins for Hyperbodies’ (2002), as though it were a body, Oosterhuis invokes the notion of the building as a second sort of body. The *MuscleBody* project alludes not only with its name and shape to the inhabitation of an intrauterine space (especially when the colour of the fabric is red). It enacts those surrealist ideas of architecture composed of partial bodies through its convulsive mechanics. The programmed behaviour of the prototype explores three types of activity: (1) bored – low activity, (2) happy – high activity, (3) nervous – hyperactivity.<sup>280</sup>

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<sup>278</sup> Oosterhuis 2003a, 46.

<sup>279</sup> Oosterhuis 2003b.

<sup>280</sup> Oosterhuis et al., 2004, 303.

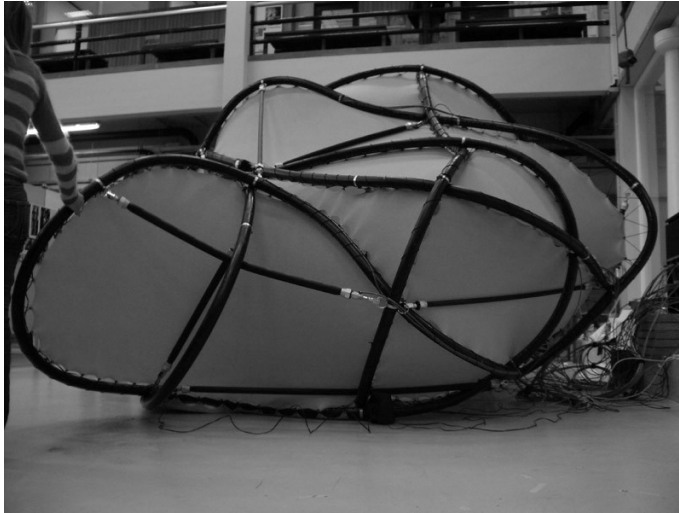


fig 4.29 Kas Oosterhuis and Hyperbody Research Group. *MuscleBody*. 2005.

The *MuscleBody* project consists of a fully kinetic and interactive architecture that is a full-scale prototype of an interior space. The project is an architectural body that consists of a continuous skin. A total of 26 industrial Festo muscles are intergraded into the structure to control the physical movement of the *MuscleBody*. In contrast to the *MuscleBody* project, where the shape is maintained by plastic tubes, the shape of the *NSA Muscle* project is maintained by an airtight membrane. The skin is composed of Lycra ®, a stretchable fabric used for sports clothing.<sup>281</sup>

These architectural prototypes are equipped with sensors; their bodies are activated via pneumatic muscles and a pneumatic shell. The softness of their envelope facilitates corporeal interaction with the soft physicality of its inhabitants. The fusion of the concept of softness and motility of organic bodies and the concept of the building as machine is inherently relevant to architecture: Softness, as a conceptual mediator between our soft body and the architecture of built environments; the machine in its role as theoretical, metaphorical and physical model of spatial organisation. As Oosterhuis points out the structural imperative of programmable, form-shifting structures is their encasing in a flexible skin.<sup>282</sup> ‘A mobile body develops a flexible skin.’<sup>283</sup> Oosterhuis points out that what makes sense as a law in nature, can also be regarded as an evolution in architecture towards buildings being equipped with skins that are ‘seamless, continuous and soft.’<sup>284</sup>

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<sup>281</sup> See <http://www.interactivearchitecture.org/musclebody-kas-oosterhuis.html>, accessed 13/11/2012.

<sup>282</sup> Oosterhuis points out that ‘[m]any of the architects of my generation still cling insecurely to a fixations on the instability of motion, but it will soon become clear to them that the art of true liquid architecture is processed in the real time balancing act of multiple forces working upon the flexible body’ (2002, 77).

<sup>283</sup> Oosterhuis 2002, 77.

<sup>284</sup> Oosterhuis 2002, 77.

## c4 | Conclusion

Transformations of elastic bodies, as evoked by Manzoli's blowing up of a balloon (in the epigraph and image at the beginning of this chapter) establish an anthropological binding between human action and the dynamic transformation of artefacts. The metabolic passage of air from human lungs into external objects carries the inspiring and animating symbology of inspiration. We are pneumatic beings. And as the human body acts as a symbolic pump, animating pneumatic bodies, the question arises whether speculations about intuitive bonding between humans and pneumatic structures emerge because of these symbolic inter-corporeal transfers. Similar speculations about corporeal transfers have already been at the heart of the surrealist architectural project [c4. s2 Surreal architectures of partial bodies]. But despite exploring fantasies of 'morphological furniture' or 'wet walls,' these visions remained unrealised and thus the physical immediacy of such visions could not be tested. But the pneumatic utopists of 1960s and 70s have found an exit strategy for their dissatisfaction with the constraint of space by stiff enclosures. Provided by rigorous basic research undertaken at Frei Otto's Institut für Leichte Flächentragwerke (IL) [c6.c3 Frei Otto's pneumatic motion systems and soft systems], new technological solutions enabled architecture to escape its mandate for stasis and permanence. 30 years later the French pneumatics utopist Antoine Stinco reflected: 'Frei Otto has just published his book on inflatable structures, and in it we found the key to our dream of escaping from [a] post-Corbusian architecture.'<sup>285</sup> Slogans such as Coop Himmelb(l)au's 'Our rooms are pulsating balloons. Our heartbeat becomes space ...'<sup>286</sup> expressed an architectural longing for corporeal immediacy between buildings and human beings. Pneumatics became the enabling technology that made those visions real – engaging corporeally and thus socially. In a similar sense plastic membranes enabled pneumatics, current technological adaptations of pneumatic, soft materials such as polymers and soft actuation technologies in experimental architectural machines and robotics might provide the key enabling technologies for aligning more flexible, thus adaptable and responsive architectures with human corporeality.

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<sup>285</sup> Antoine Stinco in Dessauce 1999, 68.

<sup>286</sup> Coop Himmelblau 2009 [1968], 16.

## PART 3

# MACHINING IT SOFTLY



## c5 | Mechanics of Softness

The soft architecture of touch – Design and construction with soft materials – Soft mechanical joints and actuators

### Introduction

When notions of spatial transformation, kinetic motion, sensibility and sensuality collapse in the architectural medium of the soft machine they are often informed by the characteristics of soft materials. The confluence of softness and the machine reveals itself to be a productive area of research, once its anthropological, material or kinetic notions (and its heterogeneities) are explored. The experimental use of soft materials such as rubbers, thermoplastic elastomers, polyurethanes, silicones or digital materials with adjustable softness gradients exerts an increasing influence on the mechanical behaviour of architectural machines. The mechanical conditions and performances of projects such as Omar Kahn's *Open Columns* (2007), Philip Beesley's *Endothelium* (2008) and *Hylozoic Ground* (2011) and my own projects, especially *Soft Machine Dementia* (2004), *Bladder Puppets* (2009), and pneumorph series *Nemone stuehp* (2013) and *Robe* (2013) [c7. s2 Pneumorphology + s3 Morphodynamic transformations and space-making] are inherently dependent on the characteristics of soft materials. But as conventional architectural description lacks the clarity necessary for the measurement of the behaviours and characteristics of soft materiality its effects cannot be fixed with proportional or geometrical exactitude.<sup>1</sup> When the terms are used, their meaning remains vague.<sup>2</sup> The necessary clarification of meaning can be obtained on a theoretical basis by looking at definitions or discussions of softness in other disciplines, but it must also be approached on a materially-experimental basis with soft materials. The newly gained knowledge can then infuse the design space in which architectural machines are conceived with knowledge about structural mechanics of soft materials.

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<sup>1</sup> In this context also see Greg Lynn's critique of conceiving architecture as an idealised, discrete and fixed prototype (1999, 13).

<sup>2</sup> See for instance 'soft' projects by Spuybroek, such as *Soft City* (1993) and *SoftSite* (1996), where – despite employing the notion of softness – no explicit explanation is provided as to how 'soft' is to be understood (Spuybroek 2004, 217 ff).



The chapter's title is a paraphrase of French philosopher Luce Irigaray's essay 'The Mechanics of Fluids' where she observes that poor theorisation and inattention to the dynamic and fluid is not accidental but rather a symptom of a 'precedence of the solid and the static.'<sup>3</sup> Irigaray notes in socio-psychoanalytical terms that the resulting structuration of language maintains 'a complicity of long standing between rationality and a mechanics of solids alone.'<sup>4</sup> Instead she proposes a structuration of language and thought in more fluid terms – one that is in her words 'continuous, compressible, dilatable, viscous, conductible, diffusible ... enjoys and suffers from a greater sensitivity to pressures...'<sup>5</sup> In similar terms it is proposed to infuse the spatial language of architecture with notions of softness.

**softness** ('softnəs) *sb.* The state or quality of being soft can be understood in various senses. This can be assigned to the character of a person (mildness, tenderness) as well as to the physical 'state, quality or property of being soft to the touch, of yielding to pressure, of lacking hardness, firmness, etc.' or the 'state or property (of a material or device) of being soft, in extended technical usage.'<sup>6</sup>

As the soft machine is positioned as an experimental medium through which soft, flexible and transformable spatial conditions can be tested the 'mechanics of softness' is proposed as its technological framework.<sup>7</sup> Omar Khan's work using elastomers (silicones) is a key reference as research into properties of soft and elastic materials inform the development of novel responsive architectural machine technologies.

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<sup>3</sup> Irigaray 1985 [1977], 145.

<sup>4</sup> Irigaray 1985 [1977], 107.

<sup>5</sup> Irigaray 1985 [1977] p 60, note 16; p 111.

<sup>6</sup> OED XV 936.

<sup>7</sup> Within this framework the construction of corporeal structures can be deployed by projecting the capacities of soft machines into architecture. The various sensual and spatial implications arising from the soft mechanical conditioning that reciprocate between soft machines and its corporeal architecture will be discussed in the next chapters.

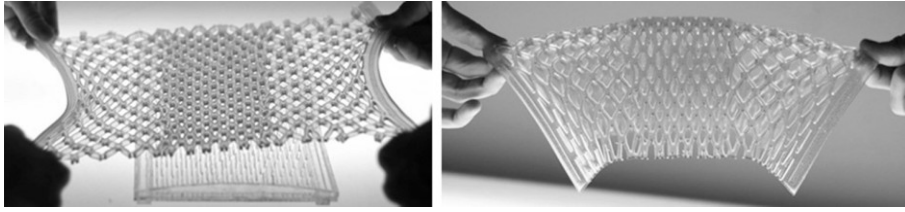


fig 5.01 Omar Khan. Exploring the elastic potential of synthetic rubbers for architectural structures. Mesh made of elastomer rubber. Screen structure of *Gravity Screens*. 2009-10.

Khan explains that soft and elastic materials perform opposite to traditional materials.

Under stress, their entropy decreases as their molecular structure becomes more ordered and they become more stable. This is easily demonstrated by pulling a rubber band which stiffens in response to the force. Traditional materials like steel, concrete and wood are designed to be static. Consequently, they exhibit increased entropy under stress. They have a small and constrained tolerance, which if pushed beyond its limits, results in material failure.<sup>8</sup>

Soft and elastic materials, on the other hand, exhibit higher stress tolerances and, when incorporated into architectural design, can potentially yield novel design strategies and solutions.

### *Chapter overview*

The approximation of mechanics of softness begins in section 1 with observations about the sensory capacities of human skin as the site for experiencing softness. From an anthropological point of view the construction of skin – the fact that it yields and gives – points to the simultaneity between softness and transformation. Section 2 examines how soft materials can be defined and how some architectural designers have incorporated the material logic of softness into their design approaches. Section 3 investigates how soft materials can inform soft architectural machine actuation technologies. A material glossary

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<sup>8</sup> Khan also points out that considered in the context of responsive architecture elastic materials seem to be better suited to accommodate the requirement for frequent mutation (Khan 2011, 55).

in Appendix 1 can be referred to for more detailed information on some typical soft materials, techniques, methodologies and terminologies.

## s1 | The soft architecture of touch<sup>9</sup>

Skin, Site of nearness – Touch, reciprocity of feeling and doing – Sensual perception of softness – Anthropocentric design mandate

‘Skin’. It keeps us together, and it gives us away.

Adrian Forty<sup>10</sup>



fig 5.02 Nicole Tran Ba Vang. *Collection Printemps. Sans titre 06*. 2001.

The human experience of softness can only be attained through sense perception via the skin. Although there are varying theories as to how the perception of softness is related to the tactile senses, there is general agreement that the perceived softness of an object is correlated with its compliance with the sense of touch.<sup>11</sup> The following section attempts to approximate the material condition ‘softness’ through a better understanding of the impressible nature of the human body and the associated sense of touch. The appreciation of these relations is fundamentally relevant to an understanding of the intricacies and potentials of the unbreakable binding of softness, touch and movement when conceiving

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<sup>9</sup> This section has been published in a modified version as ‘The soft architecture of touch’ [‘Die weiche Architektur der Berührung’] in Wihart 2011.

<sup>10</sup> Forty 2004, 51.

<sup>11</sup> Srinivasan and LaMotte 1995 + 1996; Bicchi et al. 2000. The hardness of an object is subject to its compliance, as perceived by our haptic senses. Bicchi et al (2000) state: ‘It has been firmly established in psychophysical literature that the ability of discriminating softness by touch is intimately related to both kinaesthetic and cutaneous tactile information in humans.’

soft machines. Helen Petrie et al point out that softness, understood as a material property, is 'usually taken to be a measure of compressibility.'<sup>12</sup> Consequently a material's softness can only be sensed by kinetic manipulation which in return induces the 'touch' sensation.<sup>13</sup> This inherently reciprocal relation of softness is highlighted by Petrie et al who note that the term 'softness' is 'used to describe the physical as well as sensory attributes of materials.'<sup>14</sup>

### **Skin, Site of nearness**

As the site of embodied exchange our skin engages the human body with its immediate environment.<sup>15</sup> However, the expression of skin in architectural terms as inorganic envelope or membrane has evacuated notions of sensitivity and touch. As Adrian Forty laments, architectural theory suffers from an uninformed appreciation, or 'poor knowledge of skin' which has led to a reductive metaphor.<sup>16</sup> Based on Sigmund Freud's notion of human skin as inorganic envelope resistant to stimuli one could actually consider it to be as much part of the architectural environment as it is part of the body. Freud contemplates that skin's 'outermost surface ceases to have the structure proper to living matter, becomes to some degree inorganic and thence forward functions as a special envelope or membrane resistant to stimuli.'<sup>17</sup> But by conceptualizing skin as the porous, soft, sensitive and communicative interface between our environment and all that is beneath it, skin can become a more productive generative metaphor in architectural design.<sup>18</sup> Marcos Cruz suggests that by appreciating 'human skin as a biological condition [that] works as an important reference for all the sensibility and responsiveness that it

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<sup>12</sup> Petrie et al. 2004, 3.

<sup>13</sup> Studies into the psychophysics of touch usually measure the compliance of materials in relation to the softness of the human skin.

<sup>14</sup> Petrie et al. further point out that '[p]hysically soft materials do not necessarily have the most desirable characteristics of soft materials in a sensory sense: compare the feeling of a rotting melon with a feather pillow' (Petrie et al. 2004, 2).

<sup>15</sup> The view that the skin is a sensitive organ is only a consequence of nineteenth century efforts to understand and categorize the physiological systems of the body. In earlier models, such as Aristotle's inventory of senses, the skin did not fit the idea of a sense organ (*De Anima, Bk III: Ch.12 + 13* 1966, 601 ff).

<sup>16</sup> Forty 2004, 50-51.

<sup>17</sup> Freud 1950, 27.

<sup>18</sup> Through the skin the environment is felt throughout life, as we are always in some way *in contact*.

entails<sup>19</sup> architecture can be envisioned as an environment for more kinaesthetic experiences.

Bodies are structurally soft and seek sensitive exchange with their environment as well as proximity with other bodies via their outermost organ. Juhani Pallasmaa finds in *The Eyes of the Skin: Architecture and the Senses* that '[o]ur contact with the world takes place at the boundary line of the self through specialised parts of our envelope.'<sup>20</sup> As organically discriminate emarginations of the skin, the eye, the nose and the ear do not rely on physical impressions. We perceive of the world through these highly specialised, sensory surfaces that relate to distinct environmental patterns. But even though the ocular, olfactory and sonic senses respond to some of these patterns through specific organs, it is only through the skin as site of multiple sensations that we establish physical connection with the world outside as well as with ourselves.<sup>21</sup>

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<sup>19</sup> Cruz 2014, 38.

<sup>20</sup> Pallasmaa 2005a, 10.

<sup>21</sup> See 'Hapticity: Architecture and the senses' in Mallgrave 2010, 188; 'Neuroaesthetics' in Mallgrave and Goodman 2011, 229; Body-mind correlations in Johnson 1987.

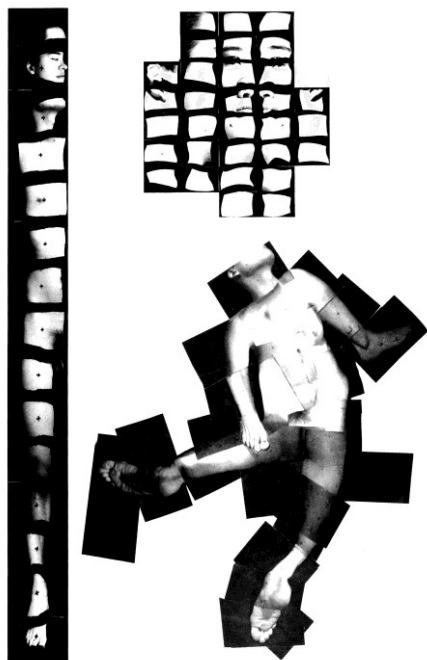


fig 5.03 Gregory Yang. *Skin*. 1993.

The work grapples with the sheer impossibility of surveying the surface of the body. Its complex surface geometry would require an infinite number of 'maps' in order to transform the body into a flat surface. Mapping out the body using architectural drawing protocols also distorts the perception of its morphological closure and thus challenges the relation between the body, the self and its surroundings in uncanny ways.<sup>22</sup>

Pallasmaa further points out the isolated sensitivity of the eye in comparison to the sense of touch: 'The eye is the organ of distance and separation, whereas touch is *the sense of nearness*, intimacy and affection. The eye surveys, controls and investigates, whereas touch approaches and caresses. During overpowering emotional experiences we tend to close off the distancing sense of vision; we close the eyes when dreaming, listening to music, or caressing our beloved ones'.<sup>23</sup> Distance, introduced by the function of the eye – the organic focal point of ocular culture – is a concept that does not apply in the world of touch. According to anthropological literature our olfactory, sonic and visual senses are 'remote senses' whereas the sense of touch belongs to 'the private senses'.<sup>24</sup> Seen from an anthropological standpoint, the sense of touch is considered to include the entire body, rather than merely

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<sup>22</sup> Yang in Hoffman 1994, 162-7.

<sup>23</sup> Pallasmaa 2005a, 46 [italics by author].

<sup>24</sup> See for instance Hall, 1969 where he set out his 'proxemic studies,' observations of the mutual relation between subjective experience and cultural rules.

discriminate parts of it.<sup>25</sup> The skin, thus, equipped with the ‘sense of nearness’ is the site of our purposive impulses for seeking closeness.<sup>26</sup> Inversely, it could be argued that we seek physical closeness because of our desire for sensations of touch.

## **Touch, reciprocity of feeling and doing**

In order to receive impressions of touch, the body needs to come into contact with the object or body from which sensory information is sought to be derived. As Petrie et al observe, the ‘sense of touch is a combination of stimulations derived from direct contact with an object’s surface, and a more general sensing of movement.’<sup>27</sup> In the act of touching lies a gesture of seeking. The reciprocal relation between touching and seeking was pointed out by environmental psychologist James J. Gibson in the 1960s. As an investigator of the sensory physiological apparatus, Gibson’s strategy was to regard the senses as seeking mechanism, rather than passive information receptors.<sup>28</sup> In understanding skin as part of a sensory seeking system, Gibson was able to combine aspects of sensual detection with aspects of bio-mechanical action.

Conceptualised in physiology as the *somatosensitive* sense, the sense of touch is a complex sensory system, coupled with the actuating, musculoskeletal framework that lies beneath it. It is more formally termed in medical sciences as ‘tactition’. The feeling ‘touch’ is produced by interplay of several sensory modalities, originating

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<sup>25</sup> Anthropologist Ashley Montagu, goes so far to point out the primacy of the haptic realm: ‘[The skin] is the oldest and the most sensitive of our organs, our first medium of communication, and our most efficient protector ... Even the transparent cornea of the eye is overlain by a layer of modified skin ... Touch is the parent of our eyes, ears, nose, and mouth. It is the sense which became differentiated into the others, a fact that seems to be recognised in the age-old evaluation of touch as “the mother of the senses”’ (Montagu 1986, 3).

<sup>26</sup> Heidegger states in *Being and Time* that ‘*In Dasein there lies an essential tendency towards closeness*’ [italics in original] (Heidegger 1962, 140). Highlighting the reciprocal relations between body and mind, it can be argued that the psychological desire for closeness is physiologically expressed in the sensitive nature of the skin and vice versa. See also Johnson 1987.

<sup>27</sup> Petrie et al, 2004, 20.

<sup>28</sup> Gibson disputed the classical theory of sensing as passive and primarily receiving, and characterizes sensing as an active act towards the environment that is ‘purposive’ and somewhat aggressive in nature. He observed that users do not wait passively for stimuli but they seek them. The user ‘explores the available field of light, sound, odor, and contact, selecting what is relevant and extracting the information’ (Gibson 1966, 32).



from the stimulation of highly differentiated receptors: *thermoreceptors* (temperature), *nociceptors* (damages to body tissues), *proprioceptors* (position of limbs) and *mechanoreceptors* (mechanical impression, strain and movement). The physical transformation that body and skin experience upon touch is predominantly sensed by the interplay of proprioceptors and mechanoreceptors and therefore the motion of touching requires the skin to be soft, flexible and sensitive all at the same time. At this most basic physical level we find expressed in the architecture of our skin the reciprocal relationship between the sensation of touch and the mechanical softness of our bodies.

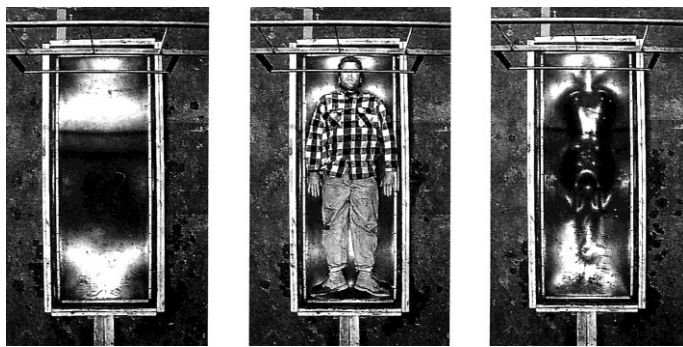


fig 5.04 Jonathan Rader. *Tomb*. 1991.

Construction of body imprint in wet concrete. Even the most rigid of materials can be treated in a fashion to infuse in it memories of softness. Due to its liquid state concrete can be shaped into almost every form.

## Sensory perception of softness

The skin is the only organ through which we can perceive softness. The mechanics embodied in the gesture of touching deforms objects that are soft and we derive comforting pleasure from touching soft objects. With the sense of touch being actively engaged – be it voluntarily or involuntarily, consciously or unconsciously – in any physical contact with our most immediate environment, the reciprocal relationship between mechanical softness and the sensitive capacity of our skin is not limited to the architecture of the skin but extends into the experience of space itself. Because we sense softness through tactile contact with our skin, objects meant to be in comforting contact with our bodies are reciprocally designed to be soft and impressionable. In her introduction to the psychology of touch Helen Petrie points out that '[m]ost of all softness is associated with the sensation of touch as touching a soft object involves sensory perception of material

compressibility, surface texture, thermal conductivity and friction.<sup>29</sup> According to Petrie the ‘psychophytic’ sensation of softness – the experience of physical touch – is coupled with the impressionability of soft materials because the sense of touch is a ‘mechanical’ sense.<sup>30</sup> Bloomer and Moore highlight the importance of the performative nature of touching for a discussion of the sense of touch in architecture in *Body, Memory and Architecture* (1996): ‘No other sense deals as directly with the three-dimensional world or similarly carries with it the possibility of altering the environment in the process of perceiving it; that is to say, no other sense engages in feeling and doing simultaneously.’<sup>31</sup>

### **Anthropocentric design mandate**

The architecture of our primal envelope instructs us, not only how we seek closeness and exchange with our most immediate environment but also how we introduce our ideas into the world. Based on the notion of architecture as ‘our collective epidermis’ Ted Krueger argued in his paper ‘Like a second skin, living machines’ (1996) for ‘a possibility of an intelligent and interactive architecture conceived of as a metadermis.’<sup>32</sup> Krueger argued that this vision could be achieved with enabling technologies, such as robotics and artificial intelligence.<sup>33</sup> Krueger points out that the material qualities of the human body, especially in the context of the epidermis, are ‘infirm, perishable, mutable and frequently anti-inert’, recalling its opposition to the durable and inert materials available in architecture, such as stone, glass, steel or concrete.<sup>34</sup>

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<sup>29</sup> Petrie et al. 2004, 2.

<sup>30</sup> Petrie et al. highlight the specific mechano-sensory performance associated with sensory experiences of soft materials when writing that ‘[s]oftness is not only associated with a passivity due to its yielding under external forces but as a physical consequence of this process it is associated with movement’ (Petrie et al. 2004, 20).

<sup>31</sup> Bloomer and Moore 1977, 35.

<sup>32</sup> Krueger 1996, 29.

<sup>33</sup> *ibid.*

<sup>34</sup> *ibid.*



fig 5.05 Bart Hess. *Slime art*. 2011.

Hess' art explores the space created between the body and the near environment by conceiving dresses as corporeal. There is something primal and immediate by seeing human bodies extended with materials that are compatible to the body's softness and flexibility.

Indeed, the propositional nature of architectural design allows us to turn the soft and sensitive logic of the human body on to technology and spatial design. Marcos Cruz has offered with his 'neoplasmatic architecture' theory a productive framework for re-scenarizing the architectural relation to skin by suggesting notions of an 'inhabitable flesh.' In his project *Hyperdermis/ Walls for Communicating People* (1999-2001) Cruz suggests a kind of 'kinaesthetic experience that is highly touch-intimate.'<sup>35</sup> The project envisions walls with integrated data suits, sensor gloves and robotic prostheses. Conventional computer screens and walls as physical boundaries are replaced with a networked bio-technological interfaces. By establishing reciprocal conditions between human, architectural and digital skins the project remaps 'the boundary between bodily interiority and exteriority, between self and building and the broader built environment.'<sup>36</sup>

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<sup>35</sup> Cruz 2014, 38.

<sup>36</sup> Cruz 2014, 39.

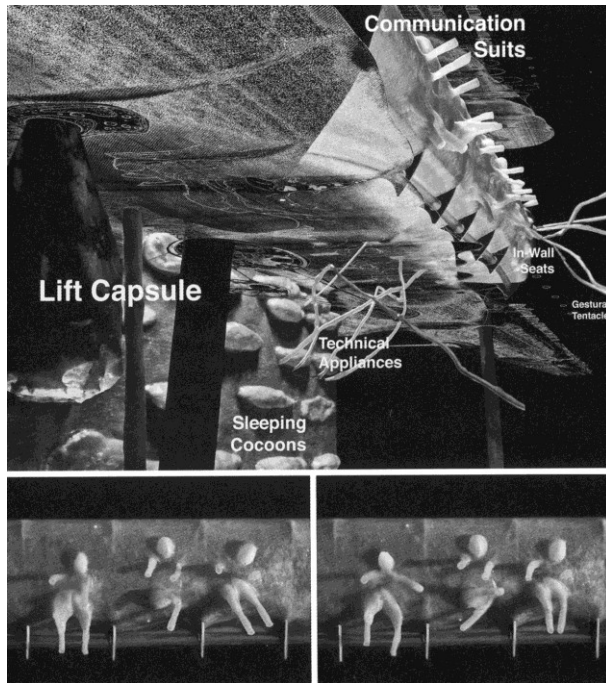


fig 5.06 Marcos Cruz. *Hyperdermis/ Walls for Communicating People*. 1999-2001.

Perspective view with communication suits, in-wall seats, storage capillaries, relaxing cocoons and gestural tentacles.

In similar ways, Kas Oosterhuis sets out an anthropocentric design agenda by complementing the architecture of the human body with the body of architecture. Oosterhuis proclaims with his *Hyperbody* thesis that '[t]he building body will act much in the same way as the biobody'.<sup>37</sup> Oosterhuis envisions architecture as an input-output device fitted with programmable 'sensory skin' that 'mediates between the environmental conditions – both external and internal – and the synthetic entity of the [building] body itself'.<sup>38</sup>

In her book *New Womb* (2000) Maria Luisa Palumbo also advocates an anthropocentric design mandate: 'While the body, invaded and dilated by technology, becomes architecture, architecture in turn looks to the body, not as a model of order and formal measurement, but as a model of sensitivity, flexibility, intelligence and communicative capacity'.<sup>39</sup> Just as we extend our bodies through technology, in turn the soft, dependable, connected, vulnerable and sensitive idea of our own bodies inspires the design of machines. The unbreakable binding of softness, motion and sensation that is embodied in

<sup>37</sup> Oosterhuis 2002, 86.

<sup>38</sup> Oosterhuis 2002, 87.

<sup>39</sup> Palumbo 2000, 80.

the architecture of our own bodies can become a design mandate for technologically extended, interfacial structures and systems [c7 Embodied architecture]. Architectural design – under the dominance of ocular culture – seems to have evacuated the sensitive human body from its virtual design realities and has remained indifferent to the new proximities between bodies, architecture and their machines.<sup>40</sup> ‘While the frontier of new relations between the body and architecture aspires towards a *sensitisation* of space, namely architecture’s aspiration to *be embodied* ... an ulterior radical transformation of the machine appears to lie at the root of this possibility.’<sup>41</sup> The inspirational site of this transformation is the primal envelope of our bodies. If the human being is the primate of architecture, the modalities of embodied contact between architecture and the human being – skin to skin, cannot ignore the reciprocal relations between mechanics of softness and sensation of touch. After all, our skin, as organ of soft and sensitive exchange, relates our body to architecture through the sense of nearness, rather than the sense of distance.

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<sup>40</sup> Quite to the contrary arts, media, exhibition design and consumer electronics have since long established physical contacts between body skins and artificial screens on the basis of mechano-sensitive exploitation of the sense of touch.

<sup>41</sup> Palumbo 2000, 6 [*italics in original*].

## s2 | Design and construction with soft materials

Specific mechanical properties of soft materials – Incorporating the mechanics of softness into architectural design

Soft material characteristics such as intrinsic mechanical behaviour, high stress tolerance, pliability or elasticity, and in some cases, programmable behaviour present a wide spectrum of design opportunities. Italian design strategist Ezio Manzini explains in his chapter ‘Creating the Soft and Pliable’ (1989) that ‘[t]he idea of softness implies complex physical performances that have to do with the way a material deforms and its reaction to deformation, the distribution of pressure, the texture and the surfaces.’<sup>42</sup> By applying these characteristics to architectural machine design, machines can overcome connotations of hardness and restrictive mechanical design. Through such strategies human behaviour, corporeal characteristics and sensitivities can be reciprocated. Manzini traces the evolution from a ‘technical culture of solid’ – expressed in the use of metal – to a ‘technical culture of solid-fluid’ – expressed in the use of plastics and polymers.<sup>43</sup> Similar developments have been observed in architectural design practice by American architect Toshiko Mori, who states that the emergence of new materials has gradually shifted design practice from ‘working within the limits of static materials to transforming them into dynamic elements.’<sup>44</sup> In order to better understand ‘softness’ in material terms, and in terms of its potential as generative design tool, this section initially examines the characteristics of soft materials and then explores the ways in which architects have incorporated these in their design.

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<sup>42</sup> Manzini 1989, 137.

<sup>43</sup> Manzini quoted in Elda Danese’s essay ‘Soft Machines’ in Katz 2003, 268; original in Manzini 1989, 67.

<sup>44</sup> Toshiko Mori 2002, xiv.



fig 5.07 Gaetano Pesce. *Pratt-Chair*. 1984.

The chair is an enquiry into the relationship between form and the solidity of material. Using the same mould but varying additives to the resin, nine chairs are created. They range from an extremely rigid chair to a chair that is so flexible that it collapses when used.<sup>45</sup>

## Specific mechanical properties of soft materials

This paragraph provides a brief outline of terms used to describe the specific mechanical properties of soft materials and a fuller description is available in the footnotes and in the appendix 1. The mechanical properties that distinguish soft materials from stiff and hard ones are generally described by how soft material behaves under external stress.<sup>46</sup> Some reactions to such influences are described as ductility, non-linear elasticity and hyperelasticity,<sup>47</sup> elongation before break<sup>48</sup> and tear strength.<sup>49</sup> Other material properties

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<sup>45</sup> Manzini 1989, 138.

<sup>46</sup> For a discussion of the relationship between mechanical properties and structure of considering elastic properties of materials see Courtney 2000, 44-84.

<sup>47</sup> In material terms, elasticity describes the mechanical behavior of many polymers and is best demonstrated with the ability of a rubber band to be stretched and then return to its original state. The Elastic modulus describes the stress / strain behaviour ( $\lambda = \text{stress} / \text{strain}$ ). Lower values indicate softer materials. Superelasticity refers to a material's ability to return to its original shape when the stress force is released.

<sup>48</sup> Elongation is the percentage of stretch that a material will exhibit prior to breaking point.

<sup>49</sup> Tear strength is the tensile force required to rupture a material sample. Materials vary in their susceptibility to tearing. Because of this variability the value of tear strength obtained depends on the shape of the test piece, speed of stretching and temperature of test. See BS ISO 34-1:2010 Rubber, vulcanized or thermoplastic: Determination of tear strength. p 7.

include plasticity and Shore hardness.<sup>50</sup> Soft materials also exhibit specific behaviour while undergoing phase changes from liquid to solid. Values such as pot life, curing time, viscosity<sup>51</sup> and dimensional variations after curing<sup>52</sup> are critical to understand when working with soft materials as these values inform the way the material can be processed.

### *Description of transformative qualities of soft materials*

Mechanical processes associated with the transformation of soft and flexible materials echoes in our language. Terms such as ‘swelling,’ ‘compressing’ or ‘pliable’ describe processes that rely on the transformation of soft material bodies. Also, a vast knowledge of physical and body acts is metaphorically used to describe soft mechanical transformations.<sup>53</sup>

Verbs	Adjectives
bend, push, pull, flex, invert, turn inside out, expand, grow, enlarge, inflate, erect, extend, thicken, swell, widen, stretch, shrink, contract, recoil, deflate, compress, constrict, squeeze, dilate.	flexible, elastic, ductile, pliable, bendable, extensible, formable, impressionable, malleable, mouldable, plastic, pliant, spongy, stretchable, tractable, yielding.

fig 5.08 Table with selected synonyms of ‘soft’ terms derived from an elicitation study for describing tactile properties of soft materials.<sup>54</sup>

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<sup>50</sup> Durometer is one of several measurement methods used to establish the hardness of a material by measuring a material's resistance to indentation. The durometer scale was defined by Albert F. Shore, who developed a measurement device called a durometer in the 1920s.

<sup>51</sup> Viscosity is the measurement of a fluid's resistance to flow. While liquids have low viscosity, pastes and creams have a high viscosity. Since viscosity is dependent on temperature, its value is meaningless until temperature is determined as well. It is essential to know the viscosity value of a material in order to control the casting process.

<sup>52</sup> Dimensional variation after curing is normally given in percentage rates. Some materials tend to shrink during curing. Especially when interfacing soft components with rigid components it is critical to understand the dimensional variation rates of a material which in prototyping can only be obtained through the production of study samples.

<sup>53</sup> For vocabulary derived from an elicitation study for describing tactile properties of soft materials (Petrie 2004, 4).

<sup>54</sup> Petrie 2004, 4.





fig 5.09 Rubber harness for *Shoe for Justine & Juliette* (for walking in slow architecture). 2007.  
Perspective view. The internal core structure of the shoe has been cast with a polyurethane rubber.

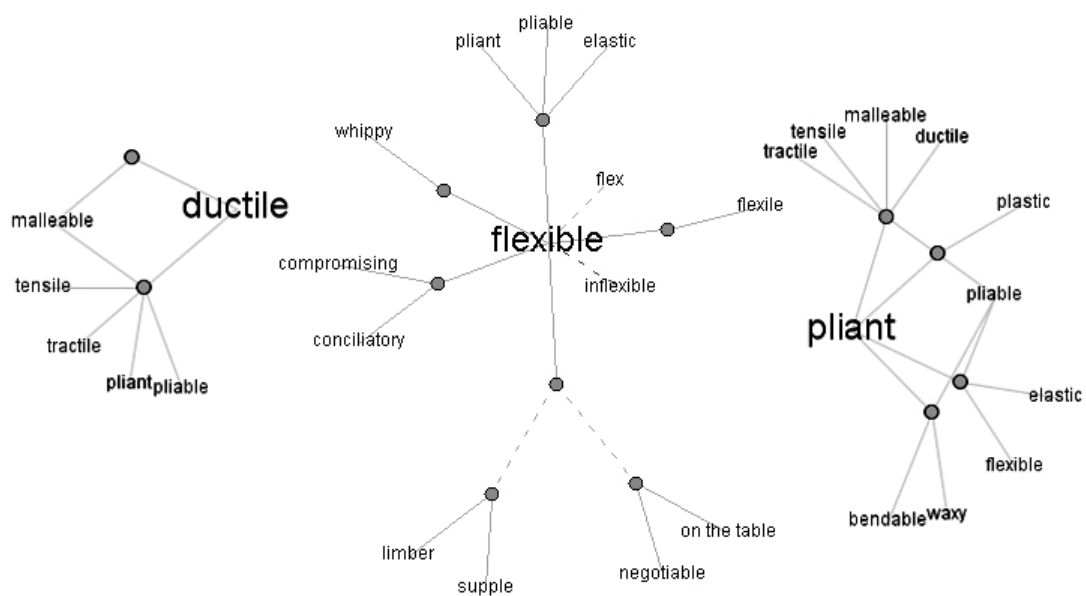


fig 5.10 The terms 'ductile,' 'flexible' and 'pliant' and related terms in branch diagram.  
Source: visual thesaurus.com.



fig 5.11 Rubber harness for *Shoe for Justine & Juliette* (for walking in slow architecture). 2007.  
Side view.

### *Inherent anthropology of soft materials*

The softness of a specific material tends to be understood in relation to the way softness is perceived through the sense of touch. But further to the sensual perception obtained through human body-material interaction, softness can also be measured empirically. Softness is measured by mechanical indentation of a material sample. The durometer is the commonly used measure for hardness in polymer, elastomers and rubbers.<sup>55</sup> There are essentially two scales relevant when working with soft materials. Shore D is used to

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<sup>55</sup> The durometer scale was defined by Albert F. Shore in the 1920s. Shore developed a measuring device called a durometer and since then the term is used to refer to the measurement as well as to the instrument itself. See US patent 1770045, A.F. Shore, 'Apparatus for Measuring the Hardness of Materials', issued 08/07/1930. The ASKER durometer is another standard used for measuring soft rubber, sponges and other foam elastomers. Other measures are for materials that are either very hard or very soft. The Bloom test provides values about the strength of gels.

measure hard rubbers and hard plastics.<sup>56</sup> This scale overlaps with the Shore A scale which is used for measuring the hardness of soft, flexible materials. The highest point on the 'A' scale, 100, is similar to the feel of the rubber of a car tire. The softest point on the 'A' scale is 00, which is the equivalent of human skin: A 0 (baby skin), 5 (face or inside of elbow) or 15 (sole of foot).

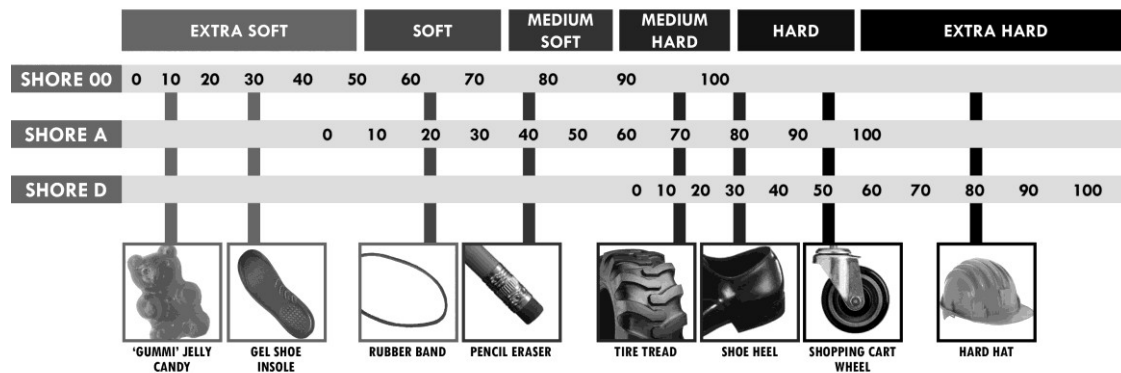


fig 5.12 Shore hardness scale ranging from very soft to very hard materials.

The shore durometer scale is a very rarely used type of specification in architecture but is the only practical way to define and communicate the softness of materials. In architectural design material is generally assumed to be hard. Assuming material softness leads to a proposition for experimenting with soft construction methodologies, conceptualised within an anthropological shore hardness spectrum.

## Incorporating the mechanics of softness into architectural design

Architecture's longstanding affinity with hard materials has been challenged by a number of architects, including Marcos Cruz, William Katavolos, Lars Spuybroek and Omar Khan, who have proposed using specific characteristics of soft materials as generative design tools or installing softness as an integral agency to architectural construction. The mechanics of softness is explored through experimental proposals and design theories.

<sup>56</sup> ASTM D2240 standard.

*William Katavolos' chemical architecture grown from polymers*

In his 1960 essay entitled 'Organics' the American architect, industrial designer and futurologist William Katavolos envisioned 'chemical architecture' characterised by its ability to be grown from soft materials such as polymers and polyurethanes.<sup>57</sup> Tapping the euphoria for new plastic technologies, he speculates: 'Double walls are windowed in new ways containing chemicals to heat, to cool and to clean, ceiling patterns are created like crystals, floors formed like corals, surfaces structurally ornamented with visible stress patterns that leap weightlessly above us.'<sup>58</sup> Katavolos articulated his 'principles of organics' by mapping out a programmatic framework for furniture that could become an active, integrated and soft mechanical component of its architectural environment. Advocating a conceptual departure from rigid mechanical frameworks Katavolos explains that this can be achieved 'without mechanics, organically in much the same manner as similar actions such as respiration, peristalsis, pulse rhythms, occur in many natural forms.'<sup>59</sup> Katavolos claimed that a chair, for instance, 'must vibrate, must flex, must massage, must be high off the floor to allow for easy access or vacation. It should also be low to the floor, when sitting, to take pressure off those areas of the body which easily constrict'.<sup>60</sup> Katavolos did not pursue his morphodynamic furniture visions,<sup>61</sup> but has recently developed his ideas through experimentations with building components constructed of liquid filled membrane structures where the outer membranes are filled with fluid at less than atmospheric pressure and, in the process create suction domes, vaults and arches within.<sup>62</sup>

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<sup>57</sup> Katavolos alludes to polymer rubbers and polyurethane foams which become commercially viable in the 1950s and 1960s. Katavolos 2007 [1960], 149.

<sup>58</sup> Katavolos 2007 [1960], 149.

<sup>59</sup> Katavolos 2007 [1960], 149.

<sup>60</sup> Katavolos 2007 [1960], 148. In another version of the manifesto Katavolos explains that the chair 'monitors body temperature, pulse and respiration, takes stool and urine samples, washes and dries while actively assisting defecation and other bodily evacuation processes' (Katavolos 2005, inset p19).

<sup>61</sup> In an interview in 2007 with Hans Ulrich Obrist, Katavolos observed that the technology that holds the most potential for the practical realisation of his 1960s speculations is today is known as nanotechnology. He explained that during his collaboration with DuPont in the 1960s engineers maintained that it would take fifty years to develop the materials required for the translation of his ideas into practical solutions, and it would take another fifty years to deploy them commercially (Katavolos 2005, inset p17).

<sup>62</sup> Katavolos 2003, 90.



fig 5.13 William Katavolos. *The Liquid Villa*. 1999.

Full-scale models demonstrating the inverted suction dome and suction columns at less than atmospheric pressure.

As Braham and Hale point out, ‘organic’ architecture for Katavolos (in contrast to Wright’s more metaphorical use of the term) describes buildings that are ‘able to react to changes in the environment and respond to the movements of the human body.’<sup>63</sup> Katavolos’ chemical architecture grown from polymers has been one of the earliest examples of turning the mechanics of soft materials onto architectural design. And if recent advancements in material sciences and soft robotics are taken into consideration, Katavolos’ speculations about architecture grown from polymers have not been unreasonable after all [c6. s1 Elastic actuations].

### *Lars Spuybroek’s Soft Constructivism*

In a range of projects Lars Spuybroek employs the concept of ‘soft constructivism’ to develop architectures informed by the mechanics of soft materials. Through experimentation with digital prototypes or material studies inspired by his meeting with Frei Otto in 1998, Spuybroek began to relate softness to architecture through the metaphor of the machine.<sup>64</sup> Spuybroek notes with regards to his *Soft Office* project (2001) that ‘the wet grid, Frei Otto’s grid, is one in which movement is structurally absorbed by

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<sup>63</sup> Katavolos 2007, 148.

<sup>64</sup> Detlef Mertens notes that Spuybroek was struck by ‘the extent to which Frei Otto’s approach resonated with his own interest in the generation of complex and dynamic curvatures.’ See Spuybroek 2004, 360.

the system; it is a combination of intensive and extensive movements, of flexibility and motion.<sup>65</sup> Although softness is predominately related to flexibility of program, the conceptual bondage of softness and the machine provides a cybernetic as well as material update of the functional bondage of machine-program. While media-based projects *Soft City* (1993) and *SoftSite* (1996) explore the impact of web-based information fluidity and user behaviour on urban space *Soft Office* employs a material based ‘machining methodology.’<sup>66</sup> ‘We needed a machine that produced open spaces for communication and closed spaces for concentration.’<sup>67</sup>



fig 5.14 Lars Spuybroek. *Soft Office*. 2001. Rubber-lacquer machine.

From left to right: (a) The rubber-lacquer machine in its building phase. Initially, the rubber tubes and the lacquer are embedded on the same level. (b) The rubber-lacquer machine in its wet phase, where the rubber lacquer is poured into the machine. (c) The rubber-lacquer machine in the separation phase, when the assembly is separated by lifting the top ring. Through this manoeuvre the lacquer is forced to stretch and interact with the rubber tubes eventually forming a three-dimensional structure.

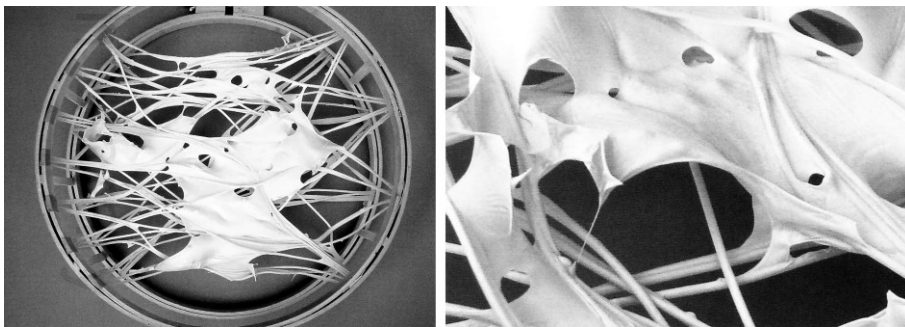


fig 5.15 Rubber-lacquer model. Overview and internal view.

The rubber-lacquer when the lacquer is fully cured. The structure’s porosity is now fully three-dimensional.

<sup>65</sup> Spuybroek 2005, 170.

<sup>66</sup> Spuybroek 2004, 217.

<sup>67</sup> Spuybroek 2004, 219.

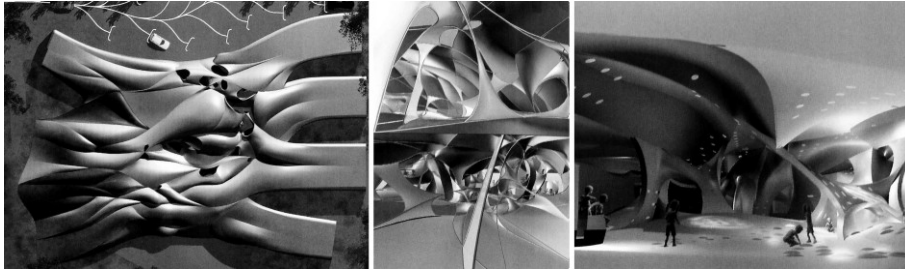


fig 5.16 Transfer of rubber model into digital space, inspiring the design space with the fluidic and morphogenetic qualities of rubber viscosity.

Spuybroek explains that softness, in the sense of flexibility, is an old rule of cybernetics. He positions architectural design as a balancing act between the ‘clarity of determinism and the fuzziness of variability.’<sup>68</sup> In his essay ‘Machining Architecture’ (2004) Spuybroek discusses the varying and overlapping ways in which architecture can be ‘machined.’ The architectural machine can involve three levels: a) at the passage of organisation to structure, b) at the passage of design to building, c) at the passage of building to experience.<sup>69</sup> Across these processes the architectural machine can be seen as a catalyst for change to the way we talk about architecture, terminologies and methodologies surrounding ideas of softness, flexibility and variability. Thus, types of spatial imagination are stimulated which have previously been inaccessible to the discipline of architecture. In conceptually close lineage with Teyssot’s ideas of a hybrid architecture as prosthetic of the human body, Spuybroek maintains that architectural machines are ‘for bodies to experience them.’<sup>70</sup> In order to consider how they relate to us, ‘we should look at how what comes out of the machine is related to what goes in.’<sup>71</sup>

### *Omar Khan’s soft kinetic gymnastics*

Soft materials – like inflatable structures, elastic assemblies and joints – demonstrate an ability to change form and reorganise space in real time. These spatial variations are induced by the performance of architectural machines constructed entirely from polymer rubber by Omar Khan at The Centre for Architecture and Situated Technologies at the

<sup>68</sup> Spuybroek 2004, 4.

<sup>69</sup> Spuybroek 2004, 12 ff.

<sup>70</sup> Spuybroek 2004, 12.

<sup>71</sup> Spuybroek 2004, 12.

University of Buffalo. Khan notes on the *Open Columns* project (2007) that it ‘re-imagine[s] ways of shaping conventional materials such as rubber, concrete, plastic and wood, using computational strategies to develop more complex relations between parts and wholes. This fundamentally challenges the static nature of these industrialized materials and sensitizes them to the ephemeral and dynamic qualities of the environments in which they are fabricated and eventually deployed.’<sup>72</sup>



fig 5.17 Omar Khan. Installation view of *Open Columns*. 2007.

The installation was built as part of the ‘Reflexive Architecture Machine’ initiative at Buffalo University, which presents a series of architecture machines that reflexively address material and information agency in the forming of space.

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<sup>72</sup> Khan 2008.





fig 5.18 Omar Khan. Detailed view of differentiated elastomere structure of the columns.

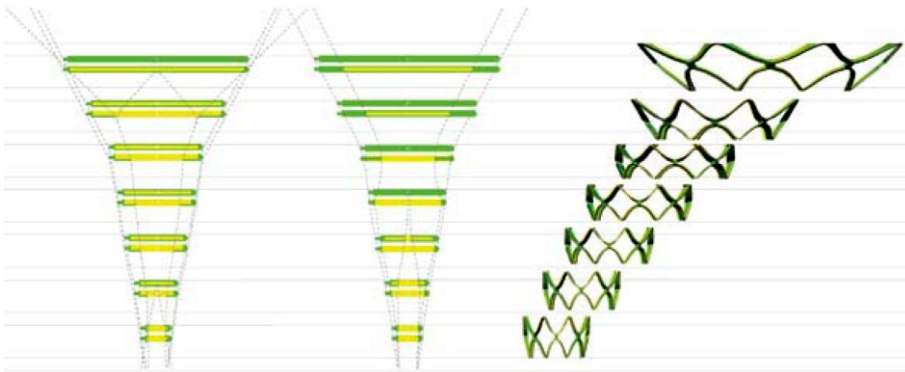


fig 5.19 Omar Khan. Drawing outlining distribution of varying Shore hardness and related elasticity. Harder = green and Softer = yellow.

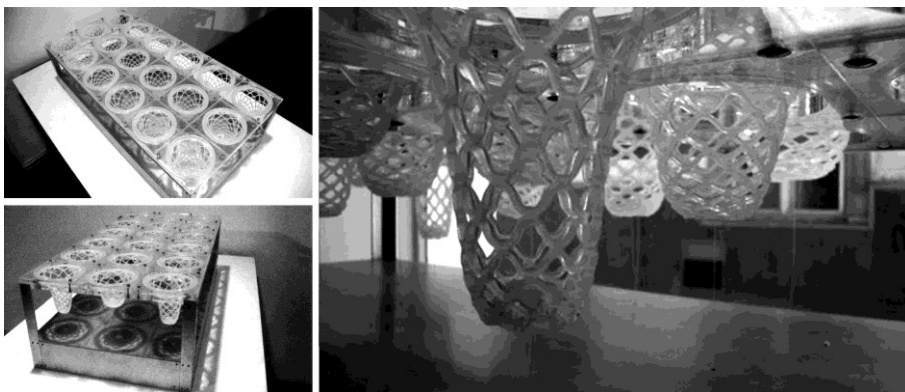


fig 5.20 Omar Khan. *Homeostat*. 2007.

A small scale precursor to *Open Columns*. The animated and flexible columns are made of a single material and can also be deployed or retracted.

With reference to Nicholas Negroponte's *Soft Architecture Machines* (1975) Khan points out that what they termed 'soft' were architecture's material and information sub-structures.<sup>73</sup> Negroponte's concept of 'soft architecture' seeks to overcome the impediments of mechanical systems which tend to make 'the most simple dwelling into a monolithic, immutable unit' and reorganise architecture around the idea of physical responsiveness.<sup>74</sup> Khan's line of research lies in 'developing direct correlations between material properties and sensing and actuating capabilities for a responsive architecture.'<sup>75</sup> Khan explains that the agenda is to focus attention on the single material property of elasticity through which cyclical and reversible changes are explored. 'Softs' would be adaptable on informational as well as on a material levels, enabling truly human-friendly adaptive and responsive architectures.<sup>76</sup>

Based on their configuration, behaviour and materiality Khan's elastic columns can be described as soft machines. They employ the soft kinetics of a flexible net typology instead of complicated Newton-based mechanics for dynamic transformation of their shape. Khan points out that the 'significance of non-Newtonian motion induction is that soft and elastic material assembly can perform 'complex formal and kinetic gymnastics without complicated connections or mechanisms.'<sup>77</sup> Khan further suggests in his article 'An Architectural Chemistry' that the conceptual shift from mechanical to sub-mechanical level in design requires looking for answers 'at the scale of the molecule and not that of the mechanical joint.'<sup>78</sup>

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<sup>73</sup> Negroponte 1975, 53.

<sup>74</sup> Negroponte 1975, 150.

<sup>75</sup> Khan 2011, 54.

<sup>76</sup> Khan 2011, 59.

<sup>77</sup> Cedric Price's seminal *Fun Palace* (1959) required multiple moving parts and complicated connections and energy-consuming machines to operate them (Khan 2011, 59).

<sup>78</sup> Khan 2011, 59.

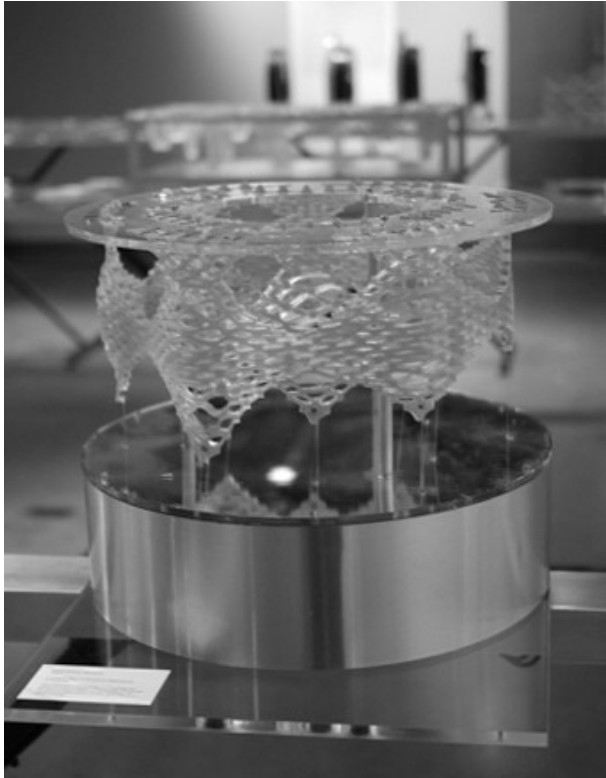


fig 5.21 Omar Khan. *Gravity Screens*. 2009-10.

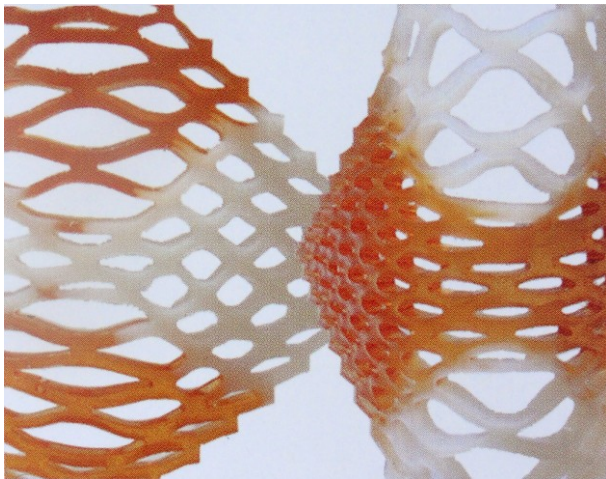


fig 5.22 Omar Khan. Elastomer study for *Gravity Screens*. 2009-10.

The geometric properties of the screens are the same but their performance is steered by the different shore hardness of the rubber. Harder = orange and Softer = white. The flexible nets are cast from silicone rubber elastomers, which exhibit non-linear elasticity and hyperelasticity. The rubber has been mixed so that it can be controlled to be more resistant against gravitational pull in relation to build-height of the structure and hence be more responsive to applied forces.<sup>79</sup>

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<sup>79</sup> Khan 2011, 58.

The elastomer columns respond to local carbon dioxide levels (human exhalation). This responsive behaviour establishes an anthropocentric binding that is reflected both in the behaviour as well as in the soft materiality of the soft architectural machine. However, the columns are not actuated with embedded actuation mechanisms, nor do they feature a motor or any other form of motion induction component. The flexible columns can only be motorless because they are external of the structure.<sup>80</sup> Alternative tactics, which hybridize motion induction and mechanical components, will be discussed in the next section.

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<sup>80</sup> Khan does not make reference to the method of motion induction used in the project. The author assumes that this traditional mechanical set-up is not discussed explicitly as it contravenes the soft mechanical ambition of the project.

It is assumed that a motor pulls or releases a cable that is connected to the frame structure at the bottom end of the column.

### s3 | Soft mechanical joints and actuators

Motion induction through soft actuators – Motion induction with soft elastic joints – Soft mechanical hybrid

As suggested by Omar Khan's 'softs' research the softening of mechanical structures can potentially overcome the restriction of Newtonian mechanical systems. While traditional systems tend to build on antagonistic conceptions of movable (dynamic actuator) and non-movable (stiff frame) parts, softening strategies warrant a hybridisation of components. The fusion of systems and materialities can potentially provide effective and innovative solutions for actuation design problems leading to lightweight construction, high power-to-weight ratio and non-linear passive elasticity. Seen within the context of historical machine developments, the integration of soft actuating components within a joint signifies an important development towards conceptions of systems as soft mechanical hybrids. I can detect these developments within my own research efforts towards softer conceptions of machines but also in the context of robotic actuation technologies that use soft and elastic materials. The difference between an actuator-frame relationship and soft actuators embedded within a joint might seem minute but they need to be seen in the context of the development of the machinic continuum towards more integrated and co-constituting conditions.

#### **Motion induction through soft actuators**

Soft actuators are flexible, elastic, lightweight and typically actuated by air pressure. Commonly referred to by a variety of terms, such as Pneumatic Artificial Muscles (PAMs), air muscles or McKibben muscles, soft actuators are often made up by an elastic internal bladder surrounded by a braided mesh shell.<sup>81</sup> Upon pressurization the internal

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<sup>81</sup> Joseph McKibben's use of these actuators in artificial limb research in the 1950s and 1960s coined the term 'artificial muscle,' although 'fluid muscles' have already been invented in 1957. See 'The Characteristics of the McKibben Artificial Muscle' in Schulte, H. F. Jr. 1961. *The Application of External Power in Prosthetics and Orthotics*. Washington D.C.: National Academy of Sciences-National Research Council. Artificial muscles or McKibben muscles were commercialized in the 1980s by a collaboration of Bridgestone Corp and Hitachi Ltd under the name 'Servo Rubbertuator.' See

bladder wants to expand into a spherical shape but because it is restricted longitudinally by the external mesh, it is instead forced to expand laterally, thus generating contraction. These soft actuators can only apply tensile forces and – although elastic – requires an antagonist actuator for effective actuation scenarios. In contrast to hydraulic or pneumatic pistons constructed from stainless steel and / or aluminium, PAMs feature lightweight construction, very high power to weight ratio and non-linear passive elasticity. PAMs are inherently compliant, meaning that when a force is exerted on the PAM, it ‘gives in.’ Industrial products such as Festo muscles were used by Kas Oosterhuis for his project *NSA Muscle* (2003). Oosterhuis used these programmable PAMs to transform the shape of an inflated balloon.

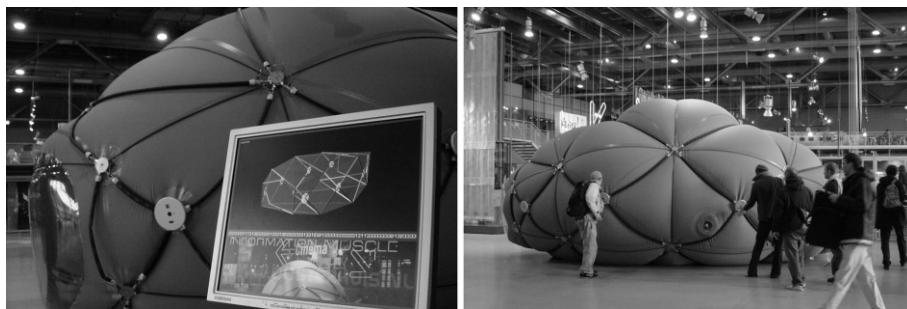


fig 5.23 Kas Oosterhuis and Hyperbody Research Group. *NSA Muscle*. 2003.

Exterior view with Festo muscles. ‘The 72 muscles are programmed to behave as 72 individual members of a swarm. Each muscle is individually informed by the brains modelled in Virtools, via 72 corresponding valves, to shrink or expand, but not without affecting the configurations of its neighbours.’

These flexible tubes become longer or shorter depending on air pressure pumped into them. Oosterhuis explains: ‘The pressurized muscles take tension forces, which must be counterbalanced by structural components that can take pressure loads. Thus I imagined an inflatable balloon wrapped in a diagrid network of connected muscles.’<sup>82</sup>

Custom built versions of air muscles have been installed in the swallowing actuators of Beesley’s *Hylozoic Ground* (2010) project. Beesley’s collaborator William Elsworth explains that ring-shaped or straight custom air-muscles produce ‘peristaltic motion in the

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‘Rubber Muscles Take Robotics One Step Further’ in *Rubber Developments*, vol 37, no 4, 1984, pp 117-119.

<sup>82</sup> Oosterhuis 2011, 118,

surrounding meshwork.<sup>83</sup> These air muscles work in a combination of '[f]ixed-length interwoven polypropylene jackets [that] restrain the inflated dimension of the muscle's latex core. Increased diameter forced by the distended latex results in shortening of the muscle.'<sup>84</sup> These components are controlled by SMA-powered pneumatic valves which are used to control air pressure and, as a result, the peristaltic motion of the assembly.<sup>85</sup>

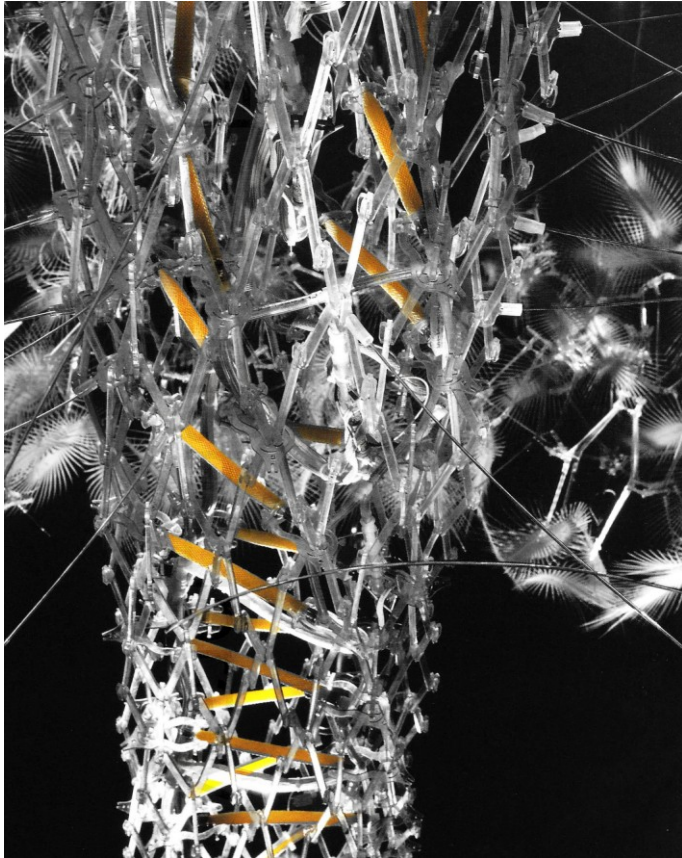


fig 5.24 Custom-made artificial muscles as part of the 'swallowing columns' in Philip Beesley's *Hylozoic Soil*. 2010.

### *Articulated Bladders*

The variation of motion induction by means of soft actuators is a central aspect of soft mechanical design, which I have studied by construction of sliding bladder joints for the *Bladder Puppets* (2010) project. This project experiments with motion induction using

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<sup>83</sup> Elsworthy in Beesley 2010, 109.

<sup>84</sup> Elsworthy in Beesley 2010, 109.

<sup>85</sup> Elsworthy in Beesley 2010, 109.



weight distribution. In this case liquids such as oil or water are transferred between the bladders. The bladders are formed of two sacks that are hanging down either side of a saddle. The bladder is balanced in such a way that it moves when liquid is transferred into a sack. With the bladders' inside abutting directly to the saddle the bladder articulates<sup>86</sup> with the saddle in the same way bones articulate with one another in an anatomical joint. In the case of the articulated bladder one part (the saddle) is rigid while the other (the bladder) is soft. The puppets are able to slide their bladders on their saddles in order to express affection and other sympathies (for each other). But because their bladders are connected they become confused as liquids are transferred from one puppet bladder to another. From a minimal pairing of two the bladder puppets are unable to perform on their own but can theoretically be networked into a swarming ecology.



fig 5.25 *Bladder puppets*. 2010. Frontal view.

Latex bladders filled with water or oil, zip laminated into latex skin in order to be able to put pumping and control equipment into inside of bladder. Silicon tubes connect sacks of the bladders. The bladders rest and slide on saddles constructed from polymer-based plaster and Wonderflex.

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<sup>86</sup> In anatomy the place where two bones are joined is called articulation (Schulte et al. 2006, 402).



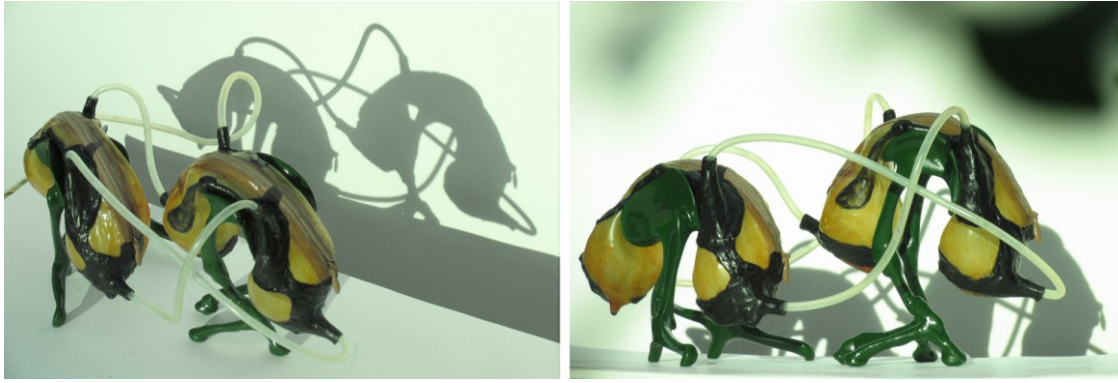


fig 5.26 *Bladder puppets*. 2010. Top and side view.

### **Motion induction within elastic joints**

Induction of motion can be located external of a joint and provided by contractile structures such as soft actuators. Alternatively, motion induction mechanisms can be embedded internally within a joint. The construction and function of an actuated joint is completely different from its musculoskeletal counterparts. Joint-based motion induction strategies can facilitate new methods of actuation and behavioural design for architectural soft machines. The potential of this motion induction strategy has been demonstrated with the pulvinus joints of *Soft Machine Dementia* [c2.s3 Biologisation of architectural machines]. Subsequent research into the use of elastic joints, bladders or bellows for pneumatic or hydraulic actuation revealed that similar research efforts have been undertaken in the area of robotics.

#### *Bellow actuators*

In the early 1980s roboticist James F. Wilson and his team at Duke University developed pneumatically actuated bellows for an experimental robot arm.<sup>87</sup> Wilson refers to the work of William M. Kier, Kathleen K. Smith, morphologist specialising in comparative biomechanic, also working at Duke University. In particular he refers to hydrostatic actuation mechanisms in soft animals such as cephalopods and elephant trunks. These structures will be of greater importance in the next chapter where actuation strategies of

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<sup>87</sup> Wilson 1984a+b. Wilson referred to these actuators also as ‘bending actuators’ and a patent is filed under US Patent No. 3981528 for a ‘Simrit finger.’

completely soft structures will be discussed in the context of the emerging field of soft robotics [c6.s1 Soft robotics and elastic actuations]. Wilson's 1980s arm actuators are made of 'partly corrugated polyurethane tubes that work as half-bellows, expanding and bending when air is pumped into them.'<sup>88</sup>



fig 5.27 James F. Wilson. Robot arm with bellow actuators. 1984.

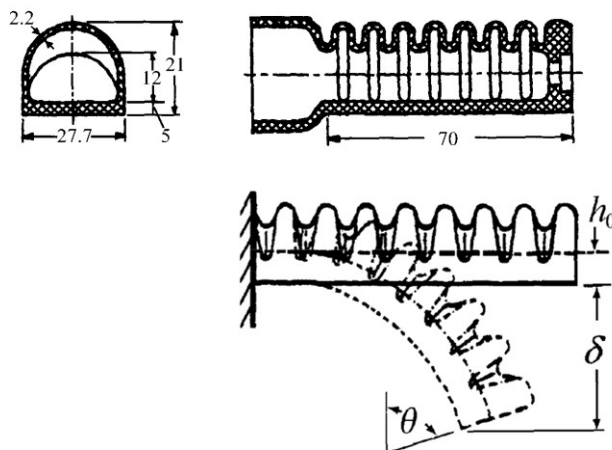


fig 5.28 James F. Wilson. Drawing of bellow actuator made of corrugated polyurethane pipes. 1984.

According to Wilson the first important study on single bellows was published by Lloyd Hamilton Donnell (1932).<sup>89</sup> However, Donnell's study was based on passive behaviour of corrugated pipes. Work on bellow pneumatic actuators for robotic grippers was also

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<sup>88</sup> Weisburd, Stefi. 'The Muscular Machinery of Tentacles, Trunks and Tongues' in *Science News*, Issue March 26, 1988; available on <http://cyberneticzoo.com/?p=6736>; accessed 04/04/2013.

<sup>89</sup> Donnell 1932.

undertaken by Nikolai Teleshev in 1981.<sup>90</sup> Dynamic actuation through pneumatics of such bellow structures was investigated by Wilson himself.<sup>91</sup>

Another venue for bio-inspired design of soft actuators has been explored more recently –inspired by spider legs<sup>92</sup> – by Ralf Becker from the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, who developed an ‘as bionic, computer-controlled lightweight robot ... fitted with elastic drive bellows that operate pneumatically to bend and extend its artificial limbs.’<sup>93</sup>

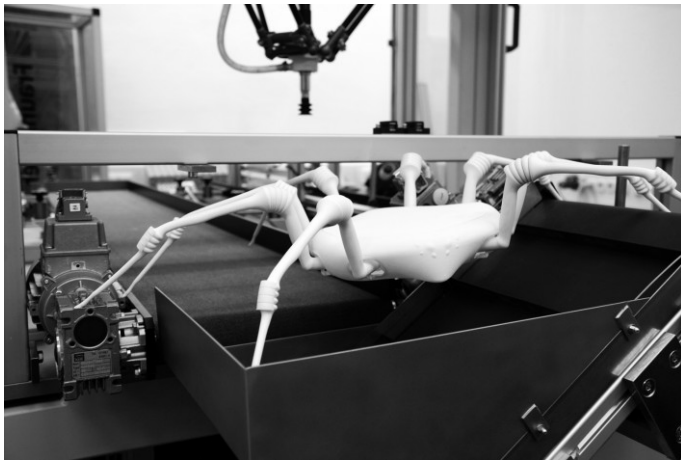


fig 5.29 *Robot spider*. Fraunhofer Institute for Manufacturing Engineering and Automation IPA, 2011. Legs and joints incorporate air supply channels and actuators made from digitally graded soft to hard materials by SLS rapid prototyping. The artificial octopod is envisioned as exploratory tool in environments that are too hazardous for humans.

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<sup>90</sup> Some information on Teleshev's corrugated pipe gripper on <http://cyberneticzoo.com/?tag=nikolai-teleshev>; accessed 2013/01/10.

<sup>91</sup> Wilson described these bellows as monolithic tubes with axially symmetric corrugations, similar to configurations discussed by Donnell (1932), Mathney (1962) or composite structures consisting of cavities embedded in moulded structures (Wilson 1984a+b).

<sup>92</sup> Foelix 1996, 21-22.

<sup>93</sup> Becker, Ralf. 'High-tech spider for hazardous missions' on Fraunhofer research news homepage, composed 2011/11/02; accessed 2013/04/05.

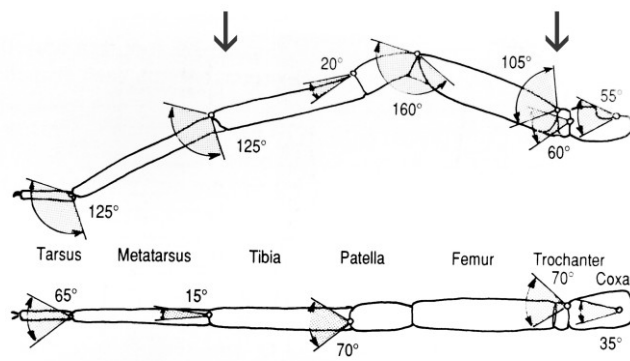


fig 5.30 Drawing showing kinetics of spider leg

The femur-patella and the tibia-metatarsal joint are hydraulic joints. They lack muscular extensors and extension is caused by an increase in hemolymph pressure,<sup>94</sup> which in turn is caused by contraction of entosternal muscles.<sup>95</sup>

Becker developed the artificial octopod prototype legs and joints in view of multi-material rapid prototyping using Selected Laser Sintering (SLS) of plastics.<sup>96</sup> Becker states that '[t]he joints have an integrated bellow made from flexible skin like structure that expands when set under pressure and move the extensions around a virtual axis.'<sup>97</sup>

### Soft mechanical hybrid

In my own work I have investigated the integration of soft, elastic bellows into joints when experimenting with the *Soft Machine Dementia* [c2. s3 Bio-inspired design in Soft Machine Dementia]. While this soft machine was actuated by a single joint, which I called a pulvinus joint, the obvious question was, whether a combination of multiple pulvinus joints could create a structure with higher degrees of motility. Following this hypothesis I constructed the *Raiser from the Ground* project (2010) on the threshold between the mechanical and the bio-inspired. The project enabled me to experiment with the material and dynamic conditions emerging between mechanical components, soft embedded

<sup>94</sup> Wilson, R.S. and Bullock, J. 'The hydraulic interaction between prosoma and opisthosoma in *Amaurobius ferox* (Chelicerata, Arancac)' in *Z. Morph. Tiere* 74 (1973) p221; Anderson, J. F. and Prestwich, K. N. 'The fluid pressure pumps of spiders (Chelicerata, Arancac)' in *Z. Morph. Tiere* 81 (1975) p257.

<sup>95</sup> Shultz 1991 in Foelix 1996, 22.

<sup>96</sup> Ondratschek 2011.

<sup>97</sup> Becker 2012, 794.

pulvinus joints and a hydraulic system. In response to the simple brief 'raising from the ground against the everlasting force of gravity' I have designed this soft machine as a physiological system where, based on hydraulic principles, liquids are transferred between various pulvinus joints. The expansion or contraction of these joints effectively converts weight and pressure of liquids into motion, enabling the soft machine to erect, interfold, maintain its balance or seek a specific posture.

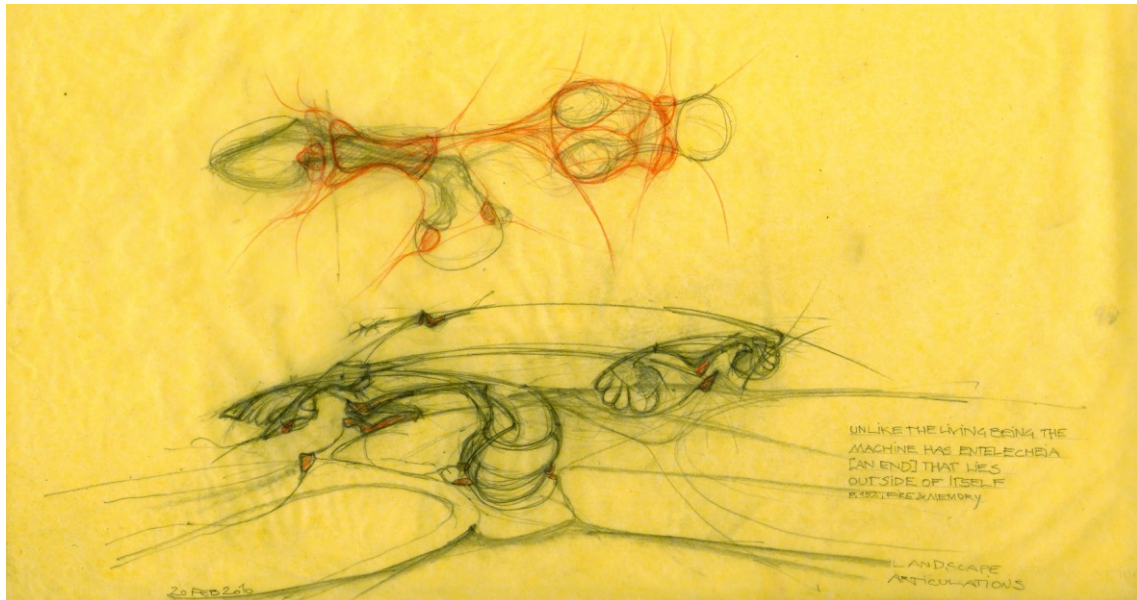


fig 5.31 Study of soft machine embedding in landscape. Plan and perspective view.



fig 5.32 Detailed study of pulvinus joint embedded in mechanical frame.

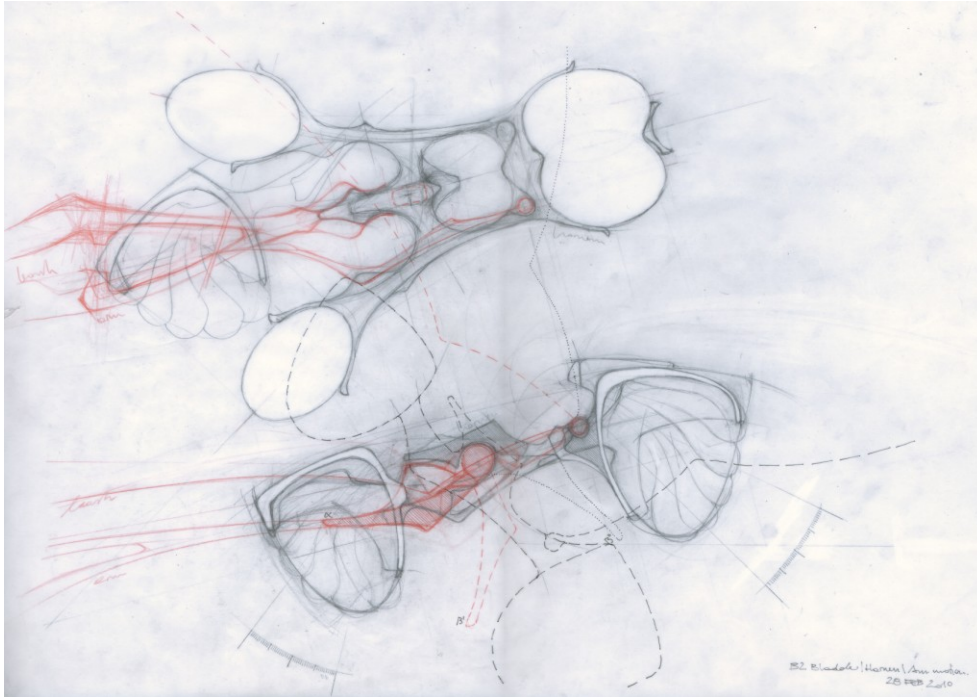


fig 5.33 Study of pulvinus joint form, layout, mechanics and harnessing in framework.

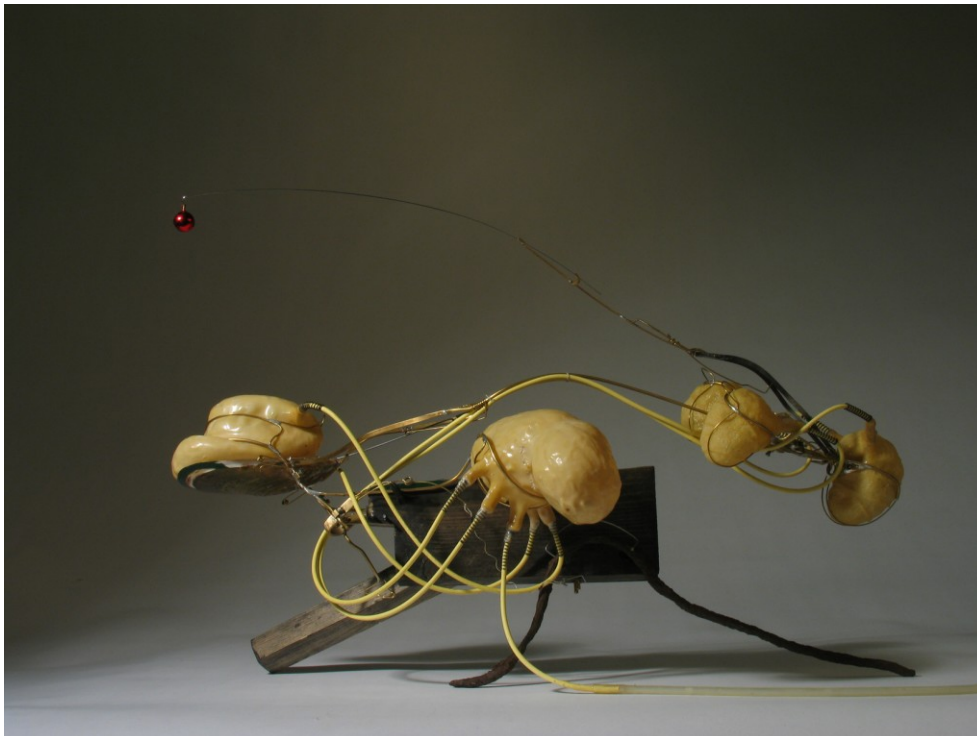


fig 5.34 Side view of mechanical frame with soft actuation components (pulvinus joints).  
Materials: silicon rubber, polyurethane rubber, timber, brass, lead, stainless steel wire, iron, gut string, sea shell, water and olive oil.



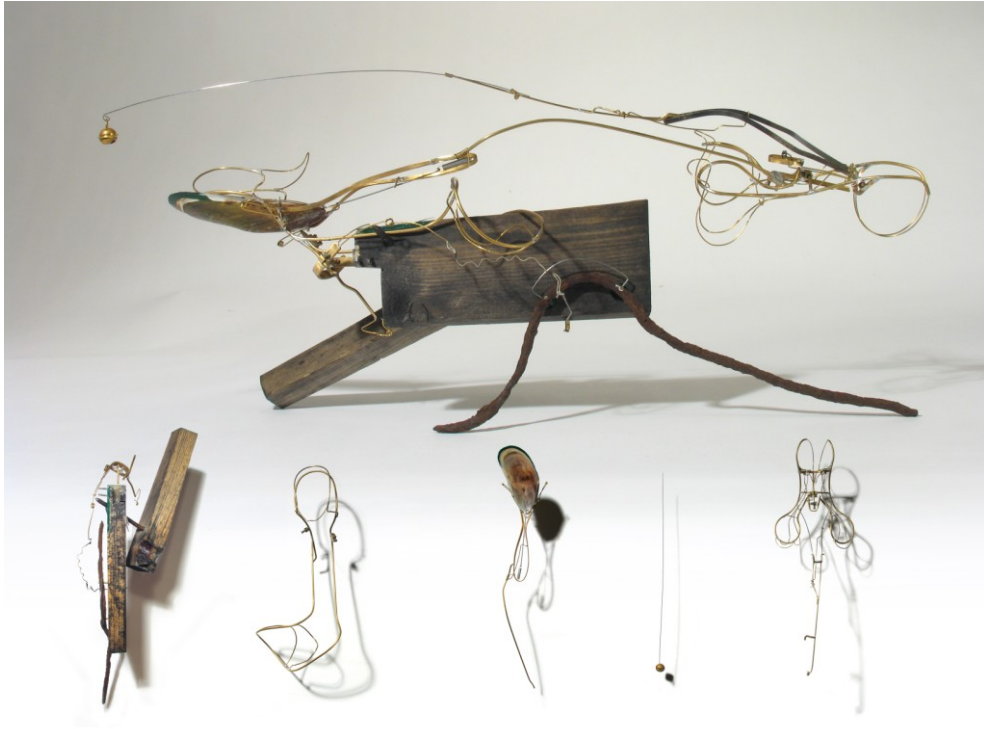


fig 5.35 Side view and frame components of mechanical frame.  
The dark piece of wood symbolizes 'ground.' The connection between the soft machine and ground is formed as a pulvinus joint that is embedded in a sea shell that is harnessed in a brass exoskeleton frame.



fig 5.36 Detailed front view of sea shell joint connecting to 'ground.'



fig 5.37 Photographs of *Raiser from the Ground* rubber pulvinus joints. Idle and swollen states of pulvinus joints induce various postures.



fig 5.38 View of *Raiser from the Ground* in raised position.



The project is also a symbolic reflection on the fundamental dilemmas of structures in motion. The *Raiser from the Ground* soft machine (as machine-human body-architecture-hermaphrodite) suggests a type of architecture that is inherently unstable, non-static and morphologically dynamic. The machine has to actively counteract the effects of gravity. Already Heinrich Wölfflin contemplated our corporeal weakness in relation to architecture in that ‘we can appreciate the noble serenity of a column’ only because we understand gravity, that is, because we have all ‘collapsed to the ground when we no longer had the strength to resist the downward pull of our bodies.’<sup>98</sup> Whenever architectures – or parts of architecture – are designed to be dynamic, gravity will inescapably have a mechanically and kinetically destabilising effect on the structure. The project further implies how dynamic buildings and landscape can relate to one another as the ultimate problem of dynamic structures is the interface of the building’s foundations with the ground. *The Raiser from the Ground* shares this debate with Oosterhuis\_Lénárd’s [ONL] project *TORS* (1993) and Greg Lynn’s *RV* (*Room Vehicle*) (2012).



fig 5.39 Oosterhuis\_Lénárd [ONL]. *TORS*. 1993.

Conceived as a 60m high building the *TORS* torso ‘balances in a bowl-shaped building pit, clearly showing that the foundations of a building must be part of the overall design.’<sup>99</sup> Oosterhuis explains that the building body theoretically ‘wobbles in the concave pit,

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<sup>98</sup> Wölfflin 1999 [1886] (also in ‘Architecture of the Senses’ in Mallgrave 2010, 201).

<sup>99</sup> Oosterhuis 2011, 170.

maintaining its active balance.’<sup>100</sup> Oosterhuis points out that when the project was conceived in the 1990s the technology to facilitate non-standard design, file-to-factory technology and inherent building interaction was not available. But projects such as Oosterhuis *NSA Muscle, Muscle Body* demonstrate that ‘embedded actuator technology is now ready to facilitate ‘the balancing act of permanent instability.’<sup>101</sup> Oosterhuis’ proposition has been put to test by Greg Lynn, when he conceived the *RV (Room Vehicle)* (2012).

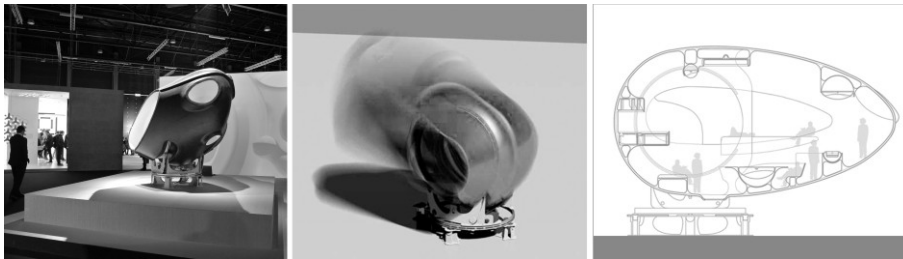


fig 5.40 Greg Lynn. *RV (Room Vehicle)*. 2012.

Made of a lightweight foam cored carbon fibre fabric the entire prototype weighs less than 50 kilos allowing it to rotate freely.

The project proposes to increase living space by rotating a specific form on two robotic axes. Appliances, furniture and building technology that would normally use up to 150 sqm can be compressed into a 60sqm footprint because living is not restricted to the floor but includes all surfaces of the *RV*. Although the rotation movement is designed to be very slow, it is still questionable how the changing internal landscape can be navigated, especially in view of its rigidity and immutability. The offering of multi-use on a mechanical platform collides with the softness and sensitivity of the human body.

In projects such as my *Raiser from the Ground*, I have speculated about the possibility of architecture learning from the experiences and capacities of human bodies. Although remaining in a much more speculative realm than Lynn’s project, experimentation with notions of soft mechanical hybridisation in *Raiser from the Ground* sought to expand its material and performative possibilities. When infused into the design of architectural soft machines, the soft and fluid mechanics of our own bodies can inspire the design of flexible and sensitive systems. Such notions can productively inform speculations about

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<sup>100</sup> Oosterhuis 2011, 170.

architecture [c7 Embodied architecture]. They may also guide criticism of projects that are dynamically conceived but adhere to rather traditional mechanical paradigms (as in the case with Lynn's *RV (Room Vehicle)*), and of earlier machinic projects such as those of Denari, Pfau and Jones [c1. s2 Technomorph machine-architecture]. These ongoing developments show that ambitions for complete hybridisation of systems, to enable them to inform each other across semiotic boundaries (morphology/ interaction/ material/ structural/ behavioural/...), are very difficult to achieve as they take departure from established design, production and construction routines and require new conceptual approaches and the development of new design and construction strategies.

## c5 | Conclusion

The chapter has shown that by conceptualizing 'softness' as part of technological methods and systems, characteristics associated with the psychophysics perception of softness can be transferred into the realm of machines. The mechanical sensation of softness – the reciprocity between sensation and movement – begins to enrich the design space of machines and architecture with behaviours and characteristics of soft materiality. The intrinsic linkage of softness with movement – the kinetic activation of soft materials through novel engineering and actuation design strategies – is the key criterion for the performance of soft machines as experimental design medium for an architecture of low Shore A hardness. In contrast to traditional, naturally sourced materials, such as stone, glass, metals or wood, most synthetic soft materials such as thermoplastic elastomers, polymers, rubbers, or silicones are moulded. They can thus be polymerized and shaped simultaneously, as French philosopher Bensaude-Vincent points out, highlighting that synthetic materials offer the possibility that 'matter and form are generated in one single gesture ... undoubtedly increasing the potential uses of such materials.'<sup>102</sup> Chris Salter has already suggested that by transforming the conception of materiality from inert to pliable through technological animation 'finally the qualities of stasis that have forever been architecture's stigma disappear.'<sup>103</sup> Speculating about the potential of this material

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<sup>101</sup> Oosterhuis 2011, 170.

<sup>102</sup> Bensaude-Vincent 2007, 295.

<sup>103</sup> Salter 2010, 105.

disruption Marcos Cruz and Steven Pike envision the material future of architecture being driven by ‘microscopic biological mechanisms and advanced manufacturing of high quality kinetic parts with new materials such as fabrics, ceramics, polymers and gels, shape-memory alloy compounds, and composites with unprecedented structural properties.’<sup>104</sup> Bio-inspired and morphological design tactics increasingly look to a ‘softer’ adaptation of natural systems. The softness of bio-inspiration and its emerging morphologies reciprocally informs the mechanics of machines, either by allowing them to passively yield under external forces or by inducing motion through soft motion induction systems. However, the ultimate departure from mechanical system thinking is signified by the imagination of structures capable of motion without mechanical joints, instead using soft mechanical solutions which can change elasticity, shape, or conductivity.<sup>105</sup> Applications of these technologies can be observed in emerging branches such as soft matter physics<sup>106</sup> or soft robotics.<sup>107</sup> Soft robotics utilise pneumatic actuation in combination with morphological design, sensing and control for ‘soft bodies composed of soft materials, soft actuators and sensors [that] will be capable of soft movements and soft and safe interaction with humans.’<sup>108</sup> [c6. s1 Elastic actuations] Current research such as undertaken at the Chair for Architecture and Sustainable Building Technologies (SuAT) at the ETH Zürich<sup>109</sup> and my own research [c6. s3 Morphodynamic transformations and space-making; c7 Embodied Architecture] explore the potential of these soft machines for architecture. Bio-inspired design tactics, enabling technologies, experimentations with soft machines made up entirely of soft materials and their potential for architectural space-making will be discussed in the next chapter.

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<sup>104</sup> Cruz and Pike 2008, 226.

<sup>105</sup> Coelho and Zigelbaum 2011, 162.

<sup>106</sup> Soft Matter Physics studies the physics of soft materials with complex properties such as natural and synthetic polymers, colloids, surfactants, and liquid crystals all of which promise new and important technological applications. Hamley 2007 and Shahinpoor and Schneider 2008.

<sup>107</sup> Soft robotics combines disciplines such as robotics, engineering, materials sciences, chemistry and biology for the application of bio-inspired design to autonomous systems and its components. Guizzo 2012; Pfeifer et al. 2012; Trivedi et al. 2008.

<sup>108</sup> Pfeifer et al. 2012, 78.

<sup>109</sup> Within the SuAT team, Dino Rossi and Zoltan Nagy are developing the Adaptive System Lab (ASL) which explores the integration of dynamic responsiveness in building performance through programming, electronics, machine learning and renewable technologies. See <http://www.suat.arch.ethz.ch/en/research>; accessed 2012/10/04.



## c6 | Really soft machines

Elastic actuations – Pneumorphology – Morphodynamic transformations and space-making.

Introducing softness into the design of robots [machines] leads to design issues that differ completely from the classical ones known from ‘hard’ type engineering, and we will thus need to elaborate a novel set of design principles.

Rolf Pfeifer, et al.<sup>110</sup>

### Introduction

Elastic and multifunctional materials will be the building blocks for a new generation of machines and robots composed entirely of soft material and fluids, says Carmel Majidi from Carnegie Mellon’s Soft Machines Lab.<sup>111</sup> Traditional structures of ‘hard’ machines are based on body plans of mammals, featuring frameworks that are typically rigid and elastic actuation components which provide power.<sup>112</sup> In similar ways, my earlier soft machines, especially *Soft Machine Dementia* (2004), *Raiser from the Ground* (2010) and *Bladder Puppets* (2009) also depend on the structural duality of actuator / framework: the pneumatic network is harnessed in a rigid mechanical framework, thus limiting the degrees of freedom (DOF). This critique of my earlier projects warranted research for actuation technologies that are intrinsically soft and where actuation is structurally embedded. Soft machines that are completely soft and elastic – freed of actuator / frame or muscle / skeleton scenarios – can potentially enable novel structural and spatial transformations. Non-mechanistic systems and enabling technologies are currently being

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<sup>110</sup> Pfeifer et al 2012b, 78. Pfeifer is Professor of computer science and director of the Artificial Intelligence Laboratory at the University of Zürich.

<sup>111</sup> Carmel Majidi in interview with Jennifer Hicks, *Forbes*, Technology, 4/22/2012, <http://www.forbes.com/sites/jenniferhicks/2012/04/22/soft-robotics-takes-shape/>, accessed 28/11/2012.

<sup>112</sup> Trivedi et al 2008, 99 and Vogel 2003.

developed in the emerging field of soft robotics, using bio-inspired approaches based around soft-bodied creatures such as worms and molluscs.<sup>113</sup>

### *Chapter overview*

Section 1, ‘Elastic actuations,’ discusses embedded actuation methodologies currently being developed in the emerging field of soft robotics. Section 2 ‘Pneumorphology’ focuses on a detailed discussion of elastic pneumatics. Based on embedded actuation methodologies that dissolve the actuator / frame duality, architectural machine components can be developed that are unrestricted by rigid mechanical components. I begin with an explanation of the principles of elastic pneumatics, and progress to a discussion of their transformational potential. Section 3 discusses the application of pneumorphology for actuation of architectural structures and their space-making capacities through morphodynamic transformation.

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<sup>113</sup> Pfeifer et al mention examples such as the tails of fish or wings of birds which passively adapt to the environment during locomotion, the elasticity of the muscle tendon system that supports coping with impact and moving over rough ground, and the deformable soft tissue in the hand and on fingertips, which is a critical property for the task of grasping hard objects (Pfeifer et al 2012b, 78). See for example the development of a robotic arm inspired by the octopus (Laschi et al 2012).

## s1 | Soft robotics and elastic actuations

Bio-inspired actuation: hydrostatic skeleton and muscular hydrostats – Embedded elastic actuation technologies.

Soft robotics introduces a radically new idea of machines into the design space for architectural machines—and ultimately for architecture: machines that not only assimilate that which is human in terms of behaviour, but also human—or in more general terms, animate—corporeality in terms of its kinetic, material and sensorial capacities. The robotics community generally defines ‘soft robots’ as: 1) machines made of soft—often elastomeric—materials, or 2) machines composed of multiple hard-robotic actuators that operate in concert, and demonstrate soft robot-like properties.<sup>114</sup> In a special issue of *Advanced Robotics*, Iida et al state that ‘soft robotics investigations typically focus on issues related to soft and deformable materials.’<sup>115</sup> The use of soft and elastic materials increases efficiency and flexibility in transformation and increases sensitivity and recognition performance both of the environment and the robot’s own body.<sup>116</sup> As a consequence of using soft materials robot designers are able to exploit ‘passive dynamics,’ facilitating movements that are more human and natural, allowing robotic systems to ‘interact with people in a soft way.’<sup>117</sup> Roboticists refer to this approach as ‘compliant,’ meaning that the soft robot gives way when force is applied to it.<sup>118</sup> Compliant robots might ‘in addition to hard components such as bones, have soft bodies made out of soft materials, soft actuators (muscles, tendons and ligaments) and sensors (soft, deformable skin with touch and temperature receptors), and will be capable of soft movements and soft interaction with people.’<sup>119</sup> Pfeifer highlights that the ‘soft’ approach will lead to robots that are more

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<sup>114</sup> Crespi et al 2005, 163-175.

<sup>115</sup> Iida et al 2012, i.

<sup>116</sup> Iida et al 2012, i.

<sup>117</sup> Pfeifer 2012a, 128.

<sup>118</sup> In engineering terms, compliance is a measure of the amount in angle or distance that a robot axis will move when a force is applied to it. When a non-compliant robot goes to a position carrying its maximum payload and drops it, the robot will overshoot vertically as the load is released. Such situations may entail health and safety risks. Compliant robots are engineered so that such movements are controlled by machine behaviour and passive dynamics.

<sup>119</sup> Pfeifer et al 2012b, 78.



adaptable and capable, as well as safer than existing robots, especially in situations where they closely interact with people in unstructured environments such as homes, offices, and public places.<sup>120</sup> The new generation of soft robots will exhibit high behavioural diversity, high degrees of bio-inspiration and design that will simplify the typically computationally intensive control through clever morphological design and use of functional materials.<sup>121</sup>

### **Bio-inspired actuation: hydrostatic skeleton and muscular hydrostats**

Actuation technologies developed in soft robotics are often inspired by systems found in soft-bodied animals.<sup>122</sup> The actuation apparatus of the starfish, the octopus, the trunk of an elephant, or the tongues of many vertebrates can facilitate complex spatial movements. These soft structures do not contain rigid parts in the form of skeletal bones or cartilage but rely entirely on differential muscle contractions.<sup>123</sup> William M. Kier, a morphologist specialising in comparative biomechanics, describes these structures as being made up by compact, three-dimensional composite of muscle and connective tissue fibres.<sup>124</sup> These structures are termed *muscular hydrostats*. In contrast, structures composed of fluid-filled cavities surrounded by fibre-reinforced containers are termed *hydrostatic skeletons*.<sup>125</sup> These structures are found in animals including anemones, polyps, worm-like invertebrates, the feet of cephalopods and snails and mammalian and turtle penises.<sup>126</sup> In fact hydrostatic principles are at work throughout the human body. The tongue is a muscular hydrostat, while the erectile tissue in male and female genitalia is a hydrostatic skeleton. Functioning

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<sup>120</sup> Pfeifer 2012a, 128. However, this notion seems to preclude the environments' remaining passive. This would obviously need to be reconsidered in light of the fact that parts of the architectural environment itself have compliant and reactive capacities.

<sup>121</sup> Such strategies can focus on exploiting material properties such as elastomeric and flexible properties of silicones. Other strategies include 'under-actuation' where only some joints of, for example, a synthetic fish body, are actuated and the others are left passive. Pfeifer et al 2012b, 79.

<sup>122</sup> Walters 2011; Morin 2012; Pfeifer et al 2012b; Ilievski et al 2011.

<sup>123</sup> Vogel 2003, 407-422; Wainwright 1988, 325-338 and Wainwright 1976, 93 and 287ff.

<sup>124</sup> Kier 1989, 23-38 and Kier and Smith 1985, 307-324.

<sup>125</sup> Kier 2012, 1252.

<sup>126</sup> Kier 2012, 1252.

of these systems depends on the incompressible nature of liquids and the variation of the volume by muscle action.<sup>127</sup>

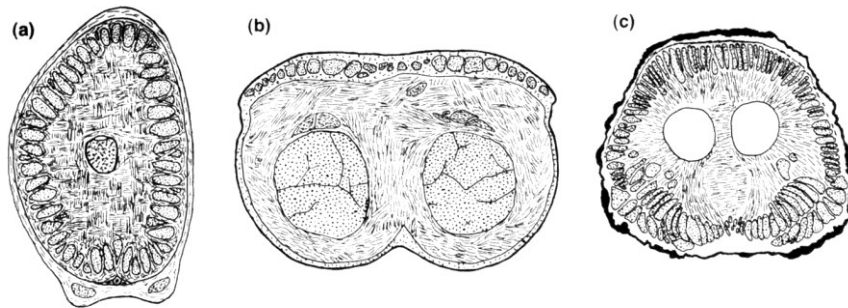


fig 6.01 Examples of Muscular hydrostats.

Cross sections of (a) squid tentacle, (b) lizard tongue and (c) elephant trunk.

(Figures from Vogel 2003, 419), see also Wainwright 1976, 93+287ff, Kier, William M. and Smith, K. K. 1985. pp 307-324.

## Embedded elastic actuation technologies

The synthetization of soft and elastic actuation technologies found in the natural world can potentially lead to new types of soft machines. Inspired by the hydrostatic principle, researchers in the robotic community are experimenting with completely new types of actuators using new materials and mechanisms that can change their structural and morphological properties.<sup>128</sup> Soft robotics researchers such as Pfeifer are optimistic that ‘fast, efficient and robust behaviour can be achieved by adequately exploiting material properties in particular “softness.”’<sup>129</sup> The challenges, however, lie in finding adequate technologies that are compliant with softness. Traditional actuation technologies such as artificial muscles, electric motors or hydraulic pistons are hard and inflexible, therefore not compliant. Pneumatic muscles rely on the muscle-skeleton duality. There are, however, some actuation technologies compliant with the softness of the morphological design of the structures they are actuating, such as shape-memory alloys, electro-active polymers, pneunets and pneubots and I will discuss these next. These structure-actuator

<sup>127</sup> Kier maintains that ‘[i]n addition to variation in the arrangement of the musculature, considerable variation exists in the form of the fluid-filled cavities, ranging from extensive cavities to solid musculature or tissue with minimal extracellular fluid’ (Kier 2012, 1249).

<sup>128</sup> Pfeifer 2012a, 124.

<sup>129</sup> Pfeifer et al 2012b, 78.

hybrids offer benefits such as material compliance and novel methodologies for the mechanical characterization of soft structures, including compliance and passive dynamics.

### *Shape Memory Alloys (SMAs)*

Exploiting the hydrostatic principle with soft technologies, soft robotics researcher Cecilia Laschi and her colleagues at the BioRobotics Institute of Scuola Superiore Sant'Anna have created an artificial octopus arm (2012). They point out the benefit of the hydrostatic principle: Muscular hydrostats act 'as a modifiable skeleton, providing stiffness when and where needed.'<sup>130</sup> A key benefit in 'imitating this muscular structure is that the muscular hydrostat creates a sort of antagonistic mechanism between different muscle fibres.'<sup>131</sup> Laschi's research team built the contractile units of the soft robotic octopus arm with SMAs combined with a particular geometry allowing the contractile range and force to be increased by using soft materials.<sup>132</sup>

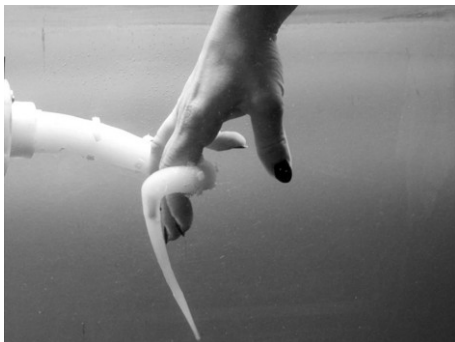


fig 6.02 Cecilia Laschi et al. *Soft robotic octopus arm*. 2012.

Actuation is obtained with cables (longitudinally) and with shape memory alloy springs (transversally). The robot arm combines contractions and it can show the basic movements of the octopus arm, like elongation, shortening and bending, in water.<sup>133</sup>

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<sup>130</sup> Laschi et al 2009, 25.

<sup>131</sup> Laschi et al 2009, 25.

<sup>132</sup> Laschi et al 2012, 709-727. Note that the first prototypes of Laschi's octopus arm have been fitted with EAPs for the longitudinal muscles, which are constructed from soft silicone rubber (Laschi et al 2009, 25). Laschi et al state that the octopus actuator EAP prototype produced 20% contraction at 0.35 N of force when applying 2000V (35).

<sup>133</sup> Laschi et al 2012.

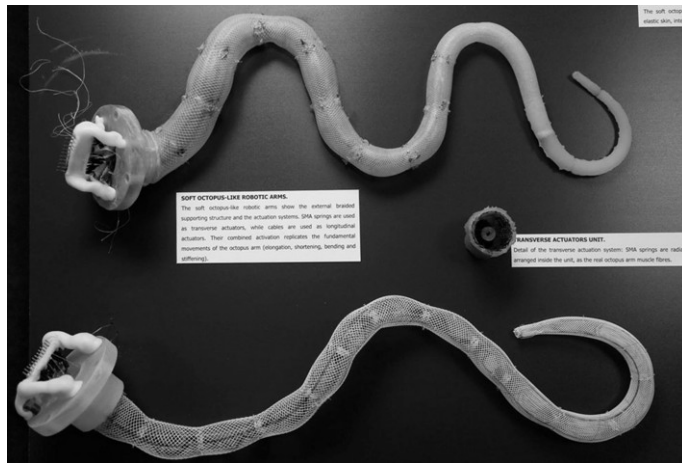


fig 6.03 Cecilia Laschi et al. Internal structure of soft robotic tentacle.  
Shown at the Institute of Biorobotics of the Italian University Sant'Anna School in Pisa. 2012.

Laschi et al state that from an engineering point of view, the modelling of an octopus arm presents interesting characteristics, such as ‘infinite number of degrees freedom (DOFs), all direction bending, capability of elongation, variable and controllable stiffness, high dexterity, fine manipulation capabilities, highly distributed control.’<sup>134</sup> In the octopus the arm movements are created by a combination of simultaneous contraction and passive stretching of different groups of muscles.<sup>135</sup> These complex movements afford relatively low neurological control in the octopus arm, as control is distributed and the mechanical characteristics of the soft tissue are such that ‘the interaction with the environment (i.e. water) is exploited to simplify control.’<sup>136</sup>

In a similar research effort, Peter Walters and David McGoran of the University of West England have created a novel type of artificial muscle that closely mimics the movement and function of tentacles found in the natural world.<sup>137</sup> The prototype has been 3D

<sup>134</sup> Laschi et al 2009, 25.

<sup>135</sup> Laschi et al point out that this arrangement reduces the overall contraction requirement while the muscle structure needs to be compliant (2009, 25).

<sup>136</sup> Laschi et al note that the octopus demonstrates how behaviour is tightly related to the morphology of the body (2012, 710).

<sup>137</sup> Walters and McGoran used the facilities at the 3D Printing Lab of the Bristol University’s Centre for Fine Print Research.

printed and SMAs have been embedded inside so that the composite's structure is able to move in various directions when stimulated.<sup>138</sup>

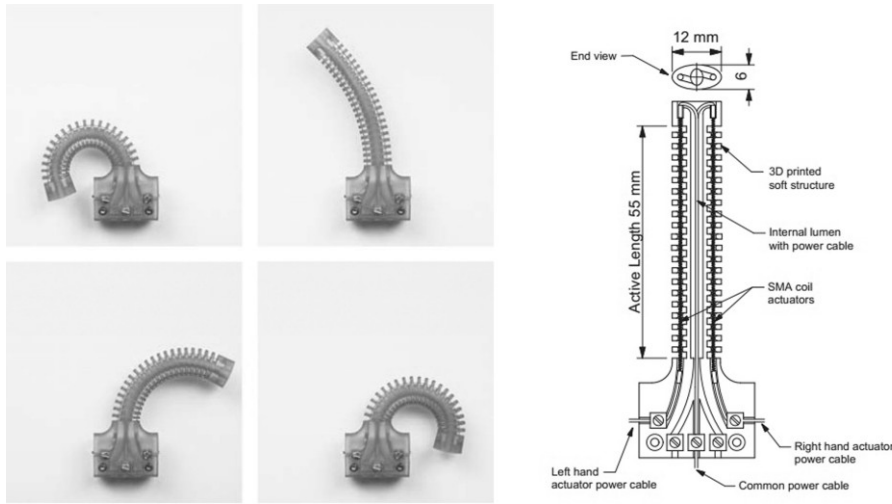


fig 6.04 Peter Walters and David McGoran. *Smart Puppet*. 2012.

Working prototype with flex sensor based analogous control interface and sectional drawing.

### *Electro-active polymers (EAPs)*

EAPs are polymers or polymer composites that can be stimulated to transform by application of electrical currents. This type of motion induction is considered to be ideally suited soft robots as they are inherently compliant and passively stretchable.<sup>139</sup> Soft robotics researcher Laschi states that EAPs are ‘filling the gap between natural muscles and artificial artefacts.’<sup>140</sup> Dielectric EAPs are composites of soft, elastic layers interspersed with metallic layers carrying an electric field. Once a high-voltage electrical field is applied the EAP is squeezed due to positive attraction of the electrical field; or alternatively due to negative attraction of the field the EAP is expanded.

<sup>138</sup> Digital Fabrication of “Smart” Structures and Mechanisms—Creative Applications in Art and Design. Peter Walters and David McGoran. Digital Fabrication 2011 Conference, NIP 27, 27th International Conference on Digital Printing Technologies, Minnesota, USA, October 2011 and <http://blog.objet.com/2012/09/04/3d-printers-help-create-artificial-muscles-for-soft-robots/>, accessed 06/03/2013.

<sup>139</sup> These characteristics allow for reversible motion engineering. The arm can be made to swing, say, to the left by applying current to contractile units at the left side, while the units at the right are not supplied. Due to them being stretchable in their passive state they do not interfere with the motion induction on the opposite side.

<sup>140</sup> Laschi et al 2009, 27.

Edyta Augustynowicz, Sofia Georgakopoulou, Dino Rossi and Stefanie Sixt developed a project that explores the potential application of electro-active polymer (EAP) at an architectural scale.<sup>141</sup> Their project *ShapeShift* (2010) is composed of thin custom made EAP layers that can induce form change of the entire structure.

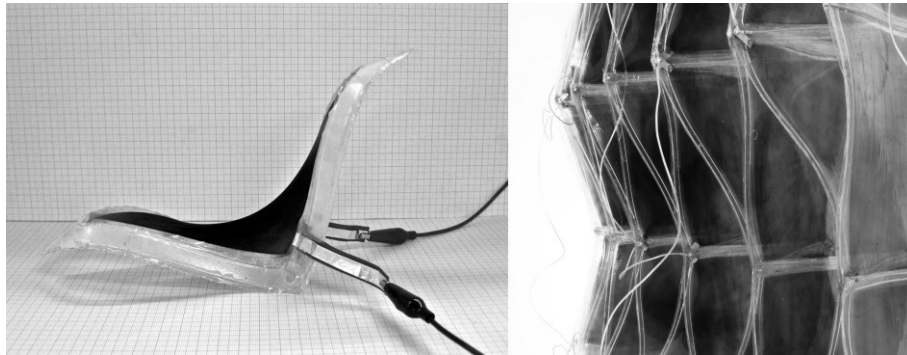


fig 6.05 Edyta Augustynowicz, Sofia Georgakopoulou, Dino Rossi and Stefanie Sixt. *ShapeShift*. 2010.

A dynamic structure working with EAPs, exploring new actuation technologies for responsive built environments. The dynamic structure is composed of custom made EAPs which are grafted onto 1.5mm thick acrylic panels. *ShapeShift* is the final thesis project of 2010 MAS students Edyta Augustynowicz, Sofia Georgakopoulou, Dino Rossi and Stefanie Sixt. The project was supervised by Manuel Kretzer at the Chair for Architecture and Sustainable Building Technologies at the ETH Zürich.

However, even though EAPs are a lightweight, flexible material capable of changing shape without the need for mechanical actuators they do have shortcomings, such as short lifecycles and high voltage requirements, which currently limit their extensive use in soft robots or other fields.<sup>142</sup>

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<sup>141</sup> <http://caad-eap.blogspot.co.uk/>; accessed 16/03/2012.

<sup>142</sup> Some EAPs only work in aqueous media (Bar-Cohen 2001), others, such as conjugated polymers and ionic polymer–metal composites have short lifecycles due to creep and material degradation (Shahinpoor, M; et al *Smart Mater. Struct.* vol 7. 1998 . insert R15.) and EAP gels require very high voltage for maximum actuation (up to 150 MV m<sup>-1</sup>) (For mechanical properties Li, X.; et al, *Mater. Sci. Eng.* 2004. vol 2. p128; for limitations Martinez 2012, 1377.

### *PneuNets (PNs)*

PneuNets (PNs) or embedded pneumatic networks (EPNs) are elastomer components fitted with channels and cavities that enable large amplitude actuation by pneumatic pressurization.<sup>143</sup>

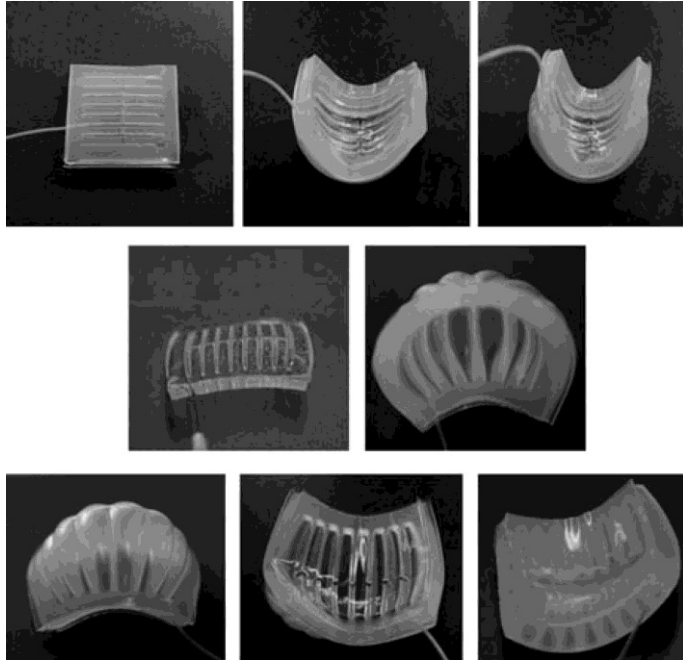


fig 6.06 Filip Ilievski et al. Prototypes for Embedded Pneumatic Networks (EPNs). 2011.

Transformation of prototypes through pressurization. Different silicone properties and shapes take influence on capacity for transformation.

Fundamental research into these soft actuating technologies has been undertaken at MIT's Distributed Robotics, the Correll Lab at University of Boulder Department of Computer Science<sup>144</sup> and at Professor George Whitesides' Research Group at Harvard. As Whitesides' colleague J. Cooper McDonald states 'forming channels in silicones and other elastomers is a well understood, widely used technique in soft lithography and microfluidics.'<sup>145</sup> One of the best known research outputs of Whitesides' research group is the Multigait soft robot designed by Robert F. Shepherd,<sup>146</sup> a small four-legged pneumatic

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<sup>143</sup> Ilievski 2011, 1890.

<sup>144</sup> Correll et al. 2010.

<sup>145</sup> McDonald and Whitesides 2001; and Qin and Whitesides 2010.

<sup>146</sup> Shepherd has since founded the Shepherd Laboratory at Cornell University specializing on soft systems.

structure that is capable of crawling by rhythmic pressurisation of its EPNs.<sup>147</sup> The technology shows principle similarities with Wilson’s bellow actuators [c6, s3] and will be discussed

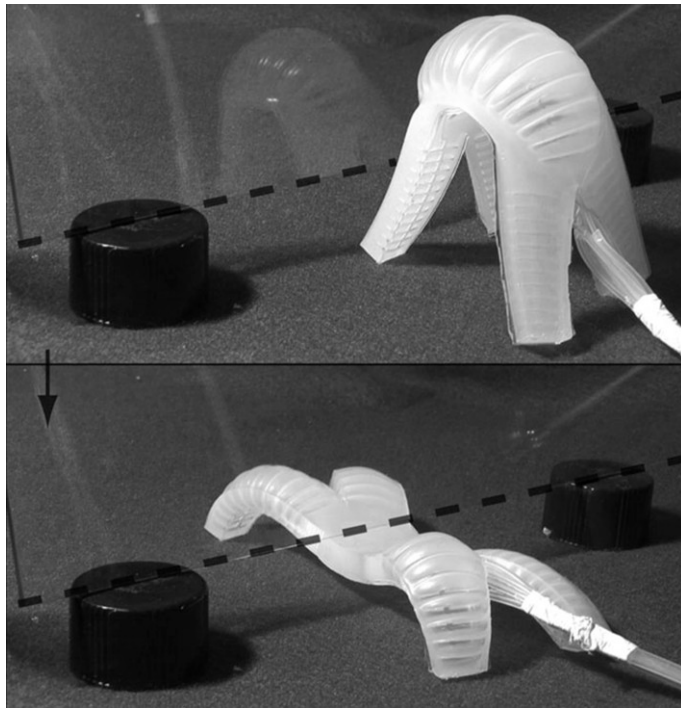


fig 6.07 Robert F. Shepherd et al. *Multigait soft robot*. 2011.

### *Pneubots*

Pneubots are textile-based inflatable robots, developed by robotics company Otherlab as part of their ‘pneubotics’ project.<sup>148</sup> Two projects discussed here are the *Inflatable Hand* or *Soft Arm* (2011), a complete, inflatable robot arm, hand and fingers, and the *Ant-Roach* (2011), a 3m long hexapod walking robot. These prototypes are completely soft and compliant, flexible, lightweight and display large strength-to-weight ratios.

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<sup>147</sup> The gait sequences were empirically determined and manually written into a spreadsheet and imported into a Lab-VIEW script that controlled the solenoid valves. Shepherd et al 2011, 2; online at [www.pnas.org/cgi/doi/10.1073/pnas.1116564108](http://www.pnas.org/cgi/doi/10.1073/pnas.1116564108), accessed 2012/10/12.

<sup>148</sup> The pneubot project was undertaken in collaboration with Meka Robotics and Manu Prakash at Stanford University, with funding from DARPA’s Maximum Mobility and Manipulation (M3) program.





fig 6.08 Otherlab. *Ant'Roach*. 2011.



fig 6.09 Otherlab. *Inflatable Hand* or *Soft Arm*. 2011.

“These robots use textile-based, inflatable actuators that contract upon inflation into specially-designed shapes to effect motion.”<sup>149</sup> Whether based on elephant trunks and cephalopod limbs, as in Wilson’s bellows (1984) [c5. s3] Laschi’s robotic octopus arm (2012), and the PneuNets, or on spider legs and pulvinus joints, as in the Fraunhofer robot (2011) or my pulvinus joint actuator based on rapid leave movement (2004) – different biological systems provided inspiration for similar technical solutions. The strategy that unites these elastic actuator systems is the application of pressure for the actuation of elastic structures.

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<sup>149</sup> Deyle, Travis. ‘Inflatable Robots by Otherlab: A Walking Robot (named Ant-Roach) and a Complete Arm (Plus Hand)’ on <http://www.hizook.com/blog/2011/11/21/inflatable-robots-otherlab-walking-robot-named-ant-roach-and-complete-arm-plus-hand>; accessed 2013/05/04.

## s2 | Pneumorphology

Elastic pneumatics – Structure and pressure in pneumorphs – Prototypes, structure and actuation design – Excuse on Hydromorphology and Microfluidics.

My own research draws inspiration from concepts and enabling technologies developed in soft robotics. They inform the next phase of my studies into the softening of machines. Actuation structures such as pulvinus joints or articulated bladders, which I have developed for actuation of earlier soft machines[c6. s3 Soft mechanical joints and actuators], although soft and elastic, are only capable of certain movements because they are harnessed in a rigid mechanical framework, thus limiting their degrees of freedom (DOF), flexibility and behavioural diversity. Motivated by this critique, my research into pneumatically actuated elastomer structures is driven by the hypothesis that structurally embedded actuation concepts can facilitate more complex spatial transformations, higher DOFs, capability of elongation and multiple direction bending. Soft robotic research has shown that these capacities are achievable while at the same time variable spatially distributed stiffness, high dexterity, passive dynamics and compliance can be facilitated by low levels of control.<sup>150</sup>

My experiments with dynamically transformable pneumatic structures led me to experiment with pneumatically actuated silicone structures capable of changing shape.<sup>151</sup> The transformative process happens without application of *external* mechanical force, but is instead induced by *internal* deployment of non-mechanical forces. The resulting non-joint based kinetics of these structures indicates potential for novel pathways for spatial design. I found it necessary to define the new field of research ‘Pneumorphology’ as existing concepts and definitions from architectural pneumatics do not include the conceptual framework required for the description of structural transformations caused by the actuation of elastic structures. In a similar sense, Ilievski and Whitesides’

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<sup>150</sup> Pfeifer et al 2012b, 79 and Laschi et al 2012, 710.

<sup>151</sup> Apart from my own design and research I am aware of research being undertaken into architectural applications of soft robotic technologies at the Assistant Chair for Architecture & Sustainable Building Technologies (SuAT), part of the Institute of Technology in Architecture (ITA) at the ETH Zürich, where researchers include Manuel Kretzer, Dino Rossi and Zoltan Nagy.

terminology ‘Embedded Pneumatic Networks’ or ‘PneuNets’ does not capture the shape-changing capacities of these structures.<sup>152</sup>

Definition of ‘Pneumorphology’ neologism			
PNEUMATICS <sup>153</sup>	+ MORPHING <sup>154</sup>	+ LOGY	= PNEUMORPHOLOGY

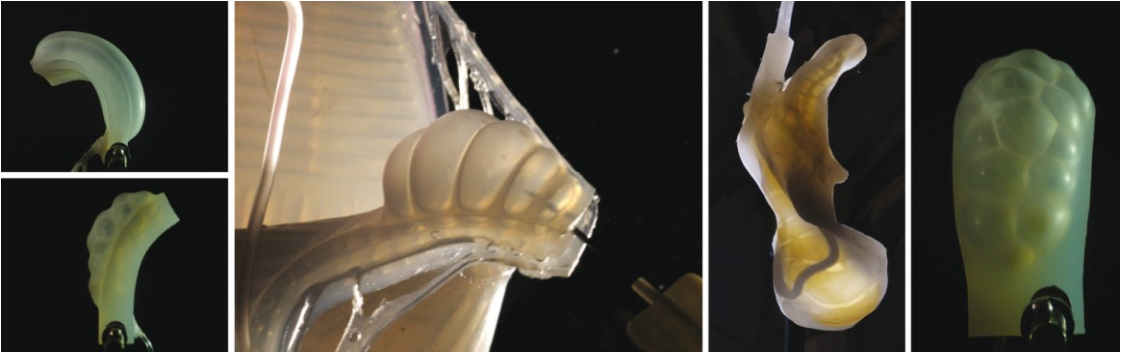


fig 6.10 Some selected pneumorph structures, including bending studies with cellular pneumorphs, pneumorphs with spawn-like structures and studies of motion induction of elastic structures by means of embedded cellular nets.

This section provides in-depth information about design and construction of prototypical pneumorphs. Possible applications of pneumorphic actuation scenarios for studies into transformational capabilities of soft architectural machines will be discussed in the next section [c6. s3 Morphodynamic transformations and space-making]. Pneumorphology is proposed as an experimental framework for the bio-inspired adaptation of the hydrostatic principle for the development of pneumatically actuated, dynamically transformable structures.<sup>155</sup> It deals with the controlled and reversible transformation of elastic forms through differential pneumatic pressurisation.

<sup>152</sup> Ilievski, Whitesides, et al 2011.

<sup>153</sup> For definition see [c2.s1].

<sup>154</sup> Morphing is a special effect in motion pictures and animations that changes (or morphs) one form into another through a seamless transition. The term is derived from the branch of biology dealing with the study of the form and specific structural features of organism (OED IX, 1091). These terms come from the Greek and are related to the term ‘metamorphosis,’ which describes the action or process of changing in form, shape or substance, and can connote a change of form by witchcraft or magic. It may also refer to the irreversible physiological changes in animals, plants or their parts, during life, especially in metabolous insects, resulting in complete alteration of form and habit. (OED IX, 675).

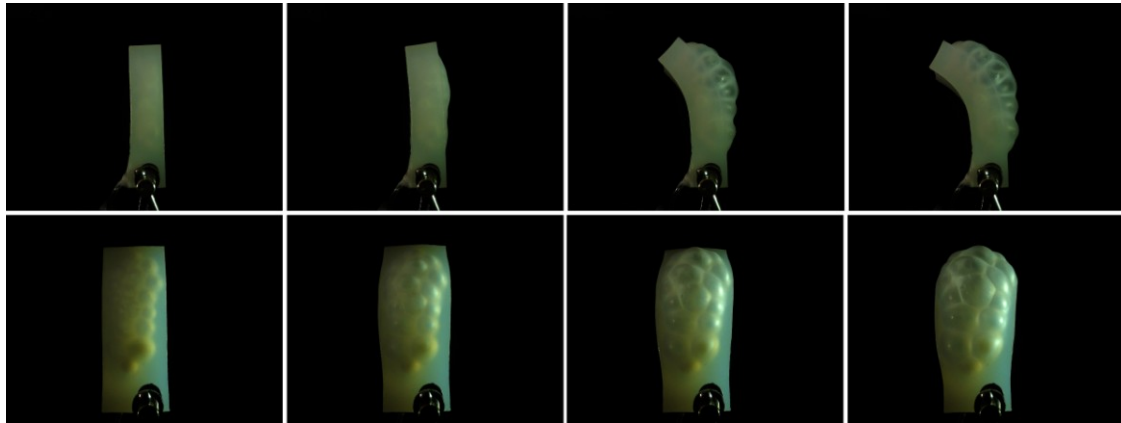


fig 6.11 Sequence of pneumorphic transformation of spawn type pneumorph prototype.

In contrast to pneumatic inflatables and convertibles constructed from rigid, non-stretchable membranes such as PVC, polyethylene foil or ETFE, Pneumorphs are constructed from elastic materials, such as polyurethane rubber, vulcanized rubber or silicone. Research has established that by employing elastic material actuation completely novel actuation scenarios including convulsive motions and high levels of freedom (DOF) can be achieved.<sup>156</sup> Further to literature-based research I have developed pneumorphic prototypes and structures in order to investigate their potential as an experimental architectural design medium. Initial prototypes discussed in this section and soft machines discussed thereafter suggest that the application spectrum could be wider than it would be for soft architectural machine experimentation alone, and speculative applications could potentially range from morphodynamic furniture [c5. s2 Katavolos] to full transformability of entire building structures [Matta in c3. s2 Architectures of partial bodies and Jungmann, Stinco, Fisher, Oosterhuis in c3. s3 Pneumatic bodies and c7].<sup>157</sup>

## Elastic pneumatics

Pneumatic technology in combination with elastic materials has a long research tradition in mechanical engineering, as discussed in the pioneering work of James F. Wilson [c6.

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<sup>155</sup> See *Excursus: Hydromorphology and Microfluidics*[c6] for the hydromorphological variation based on hydraulics.

<sup>156</sup> For details on materials and methods, see Martinez, R.V., et al *Adv. Funct. Mater.* 2012. 22. 1376–1384 and Martinez, R.V., et al *Advanced Materials*. 2013. 25. 205-212.

<sup>157</sup> Contemporary research into architectural applications of soft pneumatics is also undertaken by Daekwon Park at MIT and Dino Rossi at ETH.

s3]. Traditional pneumatic structures used in construction constrain air with rigid membranes, like an air mattress.<sup>158</sup> In contrast, pneumorphs react to pressurization by elastic expansion. Although the transformational potential of pneumatic structures has been extensively explored, the systems use tension-resistant membranes.<sup>159</sup> Pneumorphs are constructed from elastic material that is distributed volumetrically around cavities.

Elastic pneumatic structures function according to the same basic principles at work in a rubber balloon.<sup>160</sup> Filip Ilievski et al compare the expansion behaviour of soft pneumatic structures with the inflation behaviour of spherical rubber balloons.<sup>161</sup> As a result, once pressurization returns to atmospheric levels, pneumorphs will return to their original shape due to the elastic properties of elastomer materials used. The expansion force can be captured for actuation design of architectural machines. Made of elastic material and due to the fluid nature of air (or any gas used for pressurization) pneumorphs incorporate passive dynamics and are intrinsically compliant.

### Structure and pressure in pneumorphs

Ilievski et al draw attention to the advantages of the combination of soft elastomer structures and pneumatics. With ‘this type of design, complex motion requires only a single source of pressure.’<sup>162</sup> In short: the relation of applied pressure to cavity wall structure and surface area determines the kinetics of the transformation. Guiding principles can be formulated as follows:

Cavity		
Cavity wall thickness	+ Shore hardness	= Expandability
Structure		
Expandability of structure	+ Distribution of cavity	= Transformation of prototype

<sup>158</sup> Conrad Roland compares common double layer architectural pneu-structures with an air mattress (Roland in Conolly 1966, 355).

<sup>159</sup> Bubner [IL 12] 1975 and Knippers 2011.

<sup>160</sup> Needleman, Alan. ‘Inflation of Rubber Spherical Balloons,’ *International Journal of Solids and Structures*. 13. 1977. pp 409-421.

<sup>161</sup> Ilievski et al 2011, 1890-1.

<sup>162</sup> Ilievski et al 2011, 1891.

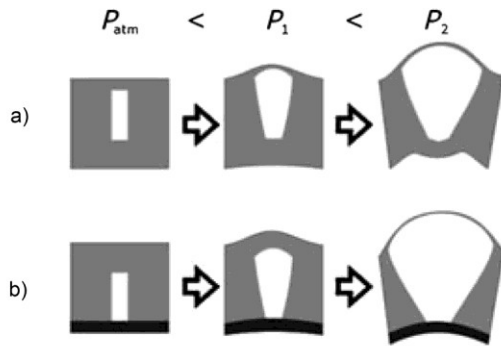


fig 6.12 Diagram of expansion of elastic container.<sup>163</sup>

a) Cavities formed in uniform elastic material; b) Channels formed in composite with cavities in softer material and stiffer material at bottom. By constraining air pressure in soft and elastic containers the architecture of these containers – their material composition and structure – is forced to respond according to the physical laws of elasticity. The cavity under pressure will seek its ideal form, which is spherical. But the ideal state is restricted by the structure of the pneumorph. Deformation of the elastic structure results in motions such as bending.<sup>164</sup>

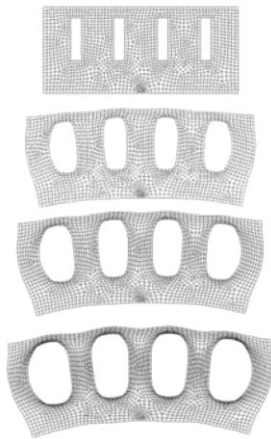


fig 6.13 Finite element analysis of cavity expansion caused by pressurisation of elastic container.<sup>165</sup>

The computational analysis of the expansion of the elastic structure shows the tendency of the cavity under pressure to obtain circular/ spherical shape.

<sup>163</sup> Expansion diagram from Ilievski 2011.

<sup>164</sup> The properties of pneumorphs are similar in principle to the way Frei Otto applied the laws of formation of soap bubbles to the construction of spherical building structures. For comparison see Conrad Roland. 'Frei Otto's Pneumatic Structures' in *Architectural Design* vol 26. issue 7. 1966. p 341-360.

<sup>165</sup> Diagram of FEA from Ilievski 2011.

The architecture of pneumorphs takes advantage of the uniform pressure distribution in pneumatics. All internal surfaces are exposed to the same amount of pressure. Therefore thinner cavity walls will expand before thicker cavity walls. Likewise cavity walls constructed from softer elastomers (lower elasticity modulus) will expand before walls constructed from harder ones (higher elasticity modulus). In a similar way, thin cavity walls will expand more than thick ones. These conditions require high level precision as even slight imperfections will cause an aneurism.<sup>166</sup>

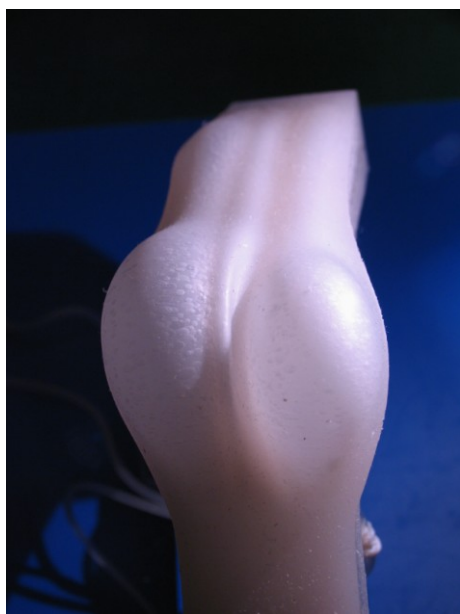


fig 6.14 Aneurism caused by imperfection in pneumorph.

The aneurism tends to become visible only during the process of inflation. In most cases wall thickness is too thin for proper function and the prototype must be deemed dysfunctional. However, aneurisms can potentially contribute to the creation of corporeal aesthetics.

When the technique fails, irrespective of their constructional and subsequent performative deficiency, aneurisms can provide interesting morphological deviations from intended results. But, in order to minimize risk of failure of pneumorphs caused by issues such as aneurisms or delamination, the design of pneumorphic structures should allow for uniform thickness of individual cavity walls and sufficient structural bonding between

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<sup>166</sup> Online supplemental material for Ilievski et al ‘Soft robotics for chemists’ in *Angewandte Chemie International Edition*. 2011. vol 50. p 6; accessed 15/02/2013. Also see Needleman’s early work on symmetrical equilibrium states in spherical and inflation of elastic structures (*Int. J. Solid Struct.* 1977. vol 13. 409-421).

components. Facilitation of distribution and redirection of pressure by the structure of pneumorphs is therefore an essential design criterion.

## **Prototypes, structure and actuation design**

Pneumorphs warrant entirely new approaches to motion planning and construction. Consequently, in a first attempt to build intuitive knowledge and understanding through empirical experimentation, the research involved material research, sample studies and the production of prototypical structures.<sup>167</sup> The two main construction methodologies explored are lost-wax casting, downstream silicone casting from 3D printed moulds, and direct 3D printing of elastic pneumorphs.<sup>168</sup> The construction of pneumorphs using digital modelling and rapid prototyping technologies has been informed by lessons learnt from analogue casting and pressurization during experimentation.<sup>169</sup>

### *Parallel cell and Spawn*

The first generation of pneumorph prototypes *Parallel cell* and *Spawn* (2013) was created in order to establish the influence of the cavity shape on the kinetics of the transformation. These silicone pneumorphs were cast using the lost-wax casting technique, and there are variations in shape, cavity to structure ratio and silicone materials used. The principal assumption was that a rigid section of the pneumorph can be bent by pressurization of a section containing cavities. As much as material selection – with a view on elasticity modulus, Shore hardness and tear strength – the actual shape and arrangement of the cavities influence the extent and directionality of the bending. These prototypes test shape-changing potential by starting out with a box shape in order to determine the transformation delta between original shape at atmospheric pressure and the pressurized prototype. For instance, by arranging rectangular shaped cavities parallel to one another as

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<sup>167</sup> In similar fashion to Whitesides' research group design and construction knowledge was build up by '[u]sing intuition and empirical experimentation [in order to] design and test prototypical structures that provide complex motion (Ilievski et al 2011, 1891).

<sup>168</sup> See appendix 2 for detailed description of construction methodologies.

<sup>169</sup> The prototypes have been pressurized using standard medical syringes, tubing and valves from giving sets and butterfly injection needles.



shown in *Parallel Cell Pneumorph 5.13* (fig 6.15), the expansion of each individual cavity is added to that of its neighbours. The sum total of all five cavity expansions generates the bending motion [c6. s3 Pneumatic precursors in architecture].

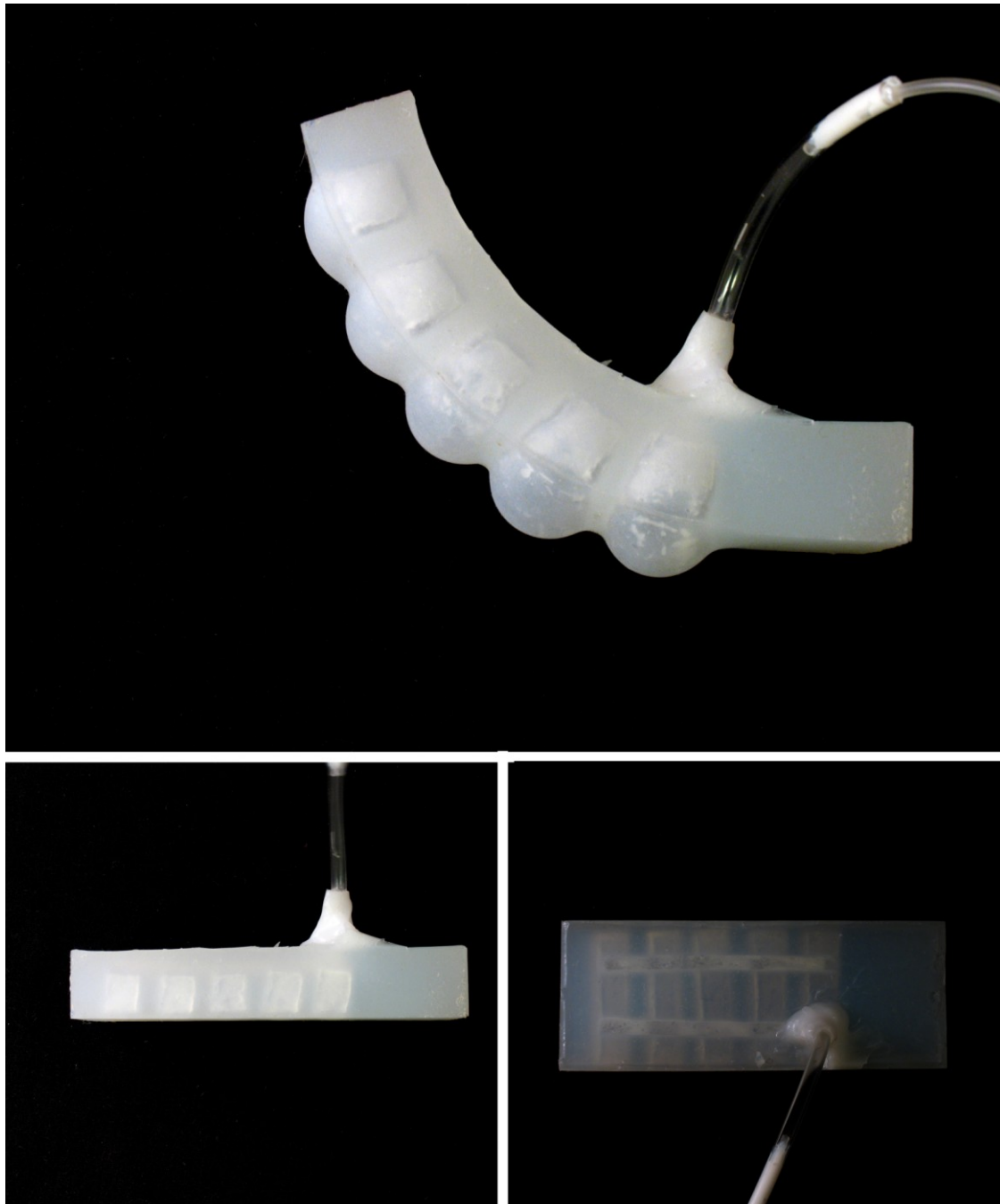


fig 6.15 *Parallel cell pneumorph 5.13*. Side view under pressure. Top view and side view in atmospheric state.

Uniform material cast prototype with axial arrangement of five cavities.

Material: Two part addition cured silicone rubber (Addition Cure 13 Silicone Rubber, Tiranti)

Material softness: Shore A hardness 13

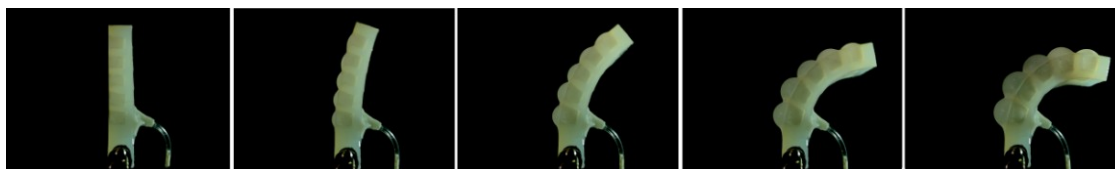


fig 6.16 Bending sequence of Parallel cell pneumorph 5.A13.

Remarkably, if cavities are arranged in longitudinal fashion as shown in *Parallel cell pneumorph 3.13* (fig. 6.17), pressurization results in similar bending actions.<sup>170</sup> Sequential pressurization of individual compartments results in a twisting action of the pneumorph. Fig 6.18 shows *Parallel Cell Pneumorph 3.00*, essentially the same pneumorph structure as *Parallel Cell Pneumorph 3.1*, but cast with very soft silicone of Shore hardness class 00-30.

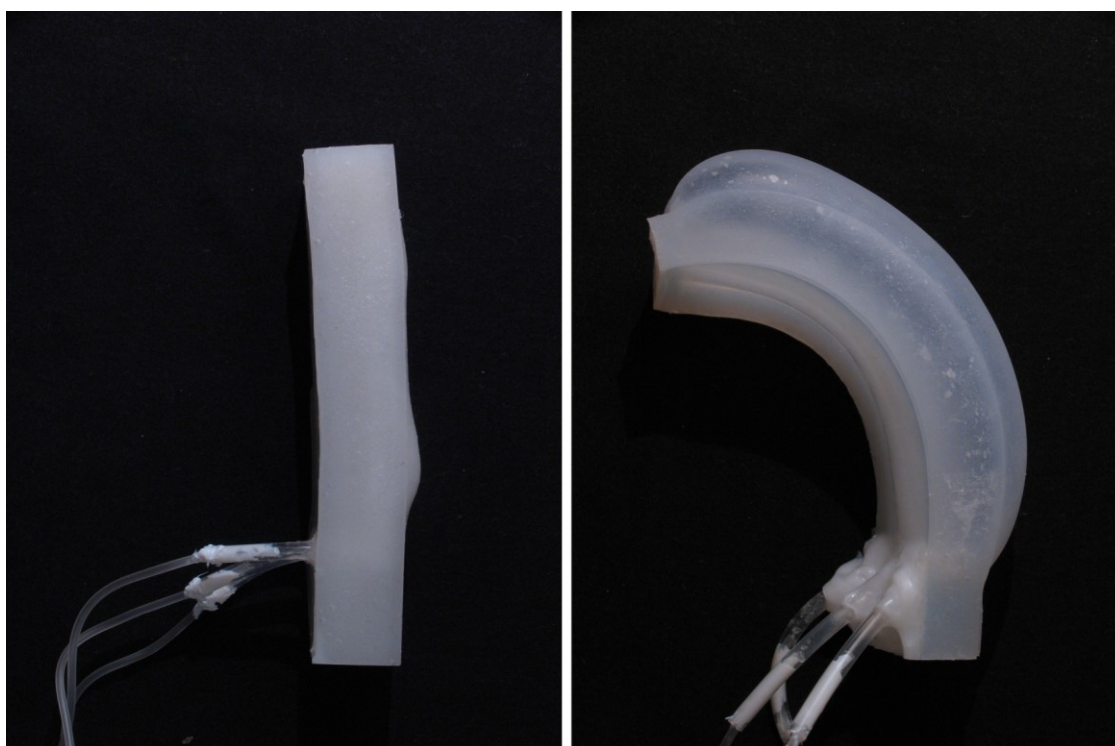


fig 6.17 *Parallel Cell Pneumorph 3.A13*. Side view in atmospheric state and under pressure.

Uniform material cast prototype with longitudinal arrangement of three cavities.

Material: Two part addition cured silicone rubber (Addition Cure 13 Silicone Rubber, Tiranti)

Material softness: Shore A hardness 13

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<sup>170</sup> For comparison online supplemental material for Ilievski et al 'Soft robotics for chemists' in *Angewandte Chemie International Edition*. 2011. vol 50. p 1; accessed 15/02/2013.

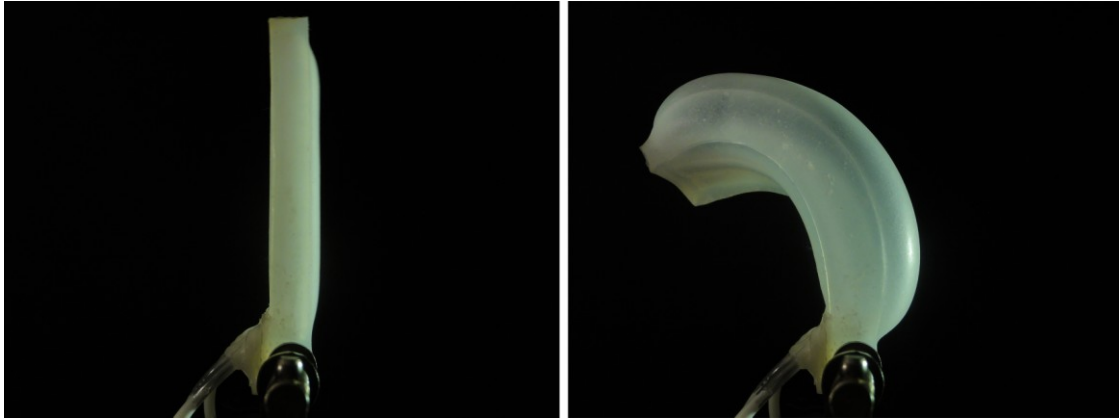


fig 6.18 *Parallel Cell Pneumorph 3.00-30*. Side view in atmospheric state and side view under pressure.

Uniform material cast prototype with longitudinal arrangement of three cavities

Material: Two part platinum-cured silicone system (Platsil Gel 00, Mould Life).

Material softness: Shore OO hardness 30

The lost wax cast for *Spawn Pneumorph Sp.A13* shown below in fig 6.19 has been constructed using a stacked arrangement of varying diameter wax spheres. The spheres have been arranged so that they touch one another. The sponge-like structure is created when the silicone fills the cavities between the spheres.



fig 6.19 Construction of spawn-type pneumorphs.

Individual spheres of wax are packed into a mould. The mould is filled with silicone and once cured and released the wax is being removed by heating the mould.

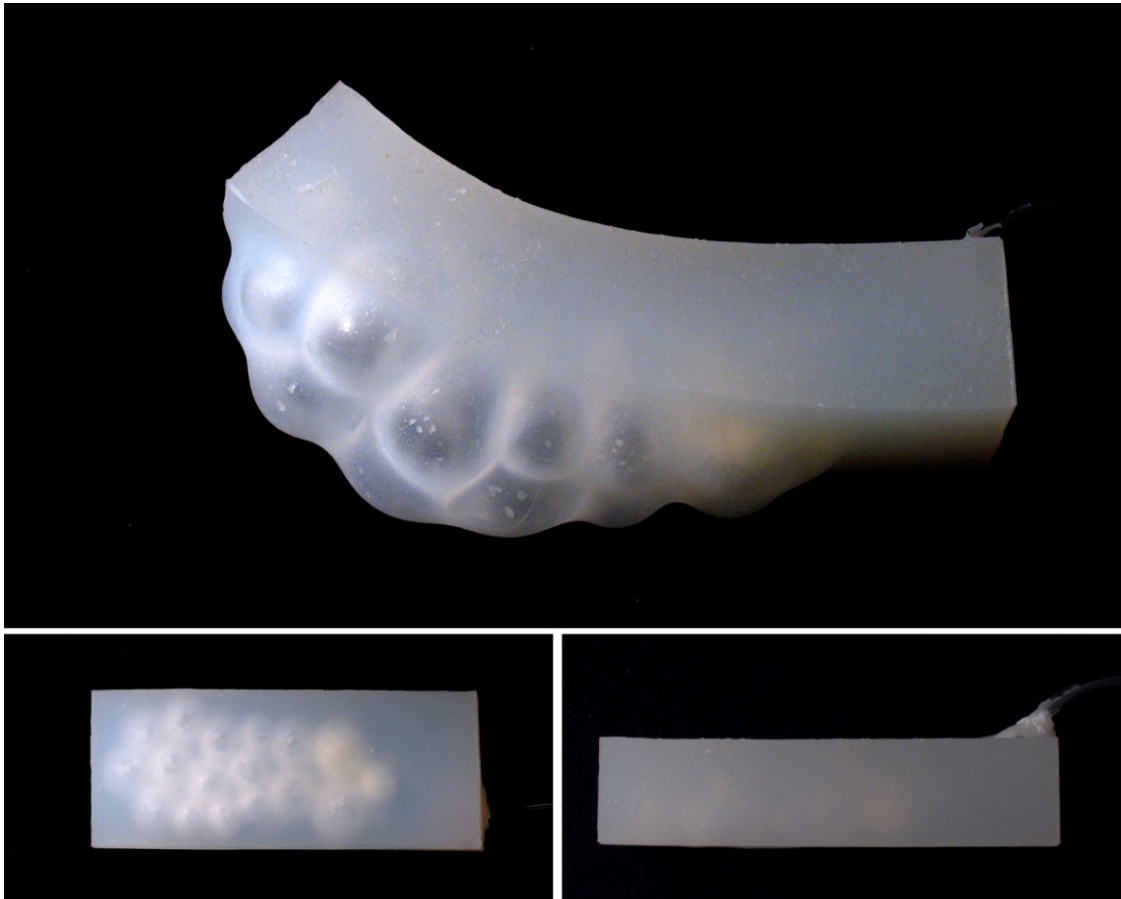


fig 6.20 *Spawn pneumorph Sp. A13*. Side view under pressure. Top view and side view in atmospheric state. Single material cast prototype with 'spawn' cavities.  
Material: Two part addition cured silicone rubber (Addition Cure 13 Silicone Rubber, Tiranti)  
Material softness: Shore A hardness 13

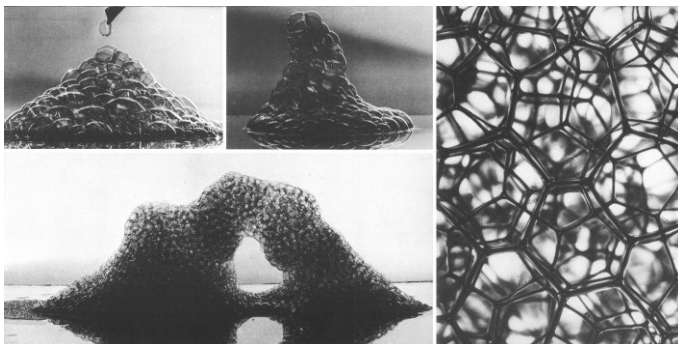


fig 6.21 Frei Otto. Bubble cluster with internal polyhedrons (Foam of soap bubbles).

The structure of the spawn pneumorph is similar to the structure found in natural organisms called spongiosa. These structures have also been studied by Frei Otto at the Institut für Leichte Flächentragwerke ([IL 19] 1979, 47 + [IL 18] 1987, 280). 'The transformation of the bubbles into polyhedrons inside the bubble cluster can be seen. The polygonal partition walls act like bracings holding the whole structure together.'<sup>171</sup>

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<sup>171</sup> Otto 1987 [IL 18], 280.



fig 6.22 David Lakatos et al. *Sponge Morphologies*. 2011.

Sponge system created by packing rubber balloons inside a rubber balloon and filling cavities with solidifying but elastic material. Variations in strength, density and elasticity of structure can be determined by spatial programming of elastic material.<sup>172</sup>

The spawn arrangement holds one significant advantage over rectangular shaped cavity arrangements: spherical cavities correlate structurally to the uniform distribution of air pressure. However, in the prototypical stage low level of control over the thickness of the sponge filaments involves higher risk of prototype failure due to rupture and resultant aneurism. Although the structural pressure correlation of spherical cavities is worth pursuing. Design of the sphere spawn cluster arrangement with computational methods and prototyping will allow higher levels of control over spawn fields configuration and distribution [c7. s3 Morphodynamic design].

### *Composition, structure and restraint*

Through prototype studies it could be established that distribution, configuration, and size of the pneumatic network determine the resulting pneumorph transformation. Further to constructing pneumorphs from single materials, composite constructions can enable more varied actuation designs.<sup>173</sup> Ilievski et al state that '[c]omposite structures, in which

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<sup>172</sup> As part of Neri Oxman's Mediated Matter group at MIT Media Lab. See Menges 2012, 95.

<sup>173</sup> The principle method for composite material casts or assembly of different components is the 'wet-in-wet' casting technique where components were bonded together while still in curing phase. Even though this technique can be complicated this technique is necessary because silicone does not bond to silicone. Due to different curing times of materials used accurate control of the casting environment (temperature, humidity) and timing is critical.

materials with different stiffness join to form a channel, are useful for programming the directionality of actuation, and provide properties that benefit from the combined mechanical properties of the different materials.<sup>174</sup> Similar to McKibben artificial muscles where the external net restrains the rubber, stiffer parts of the pneumorph dictate movement patterns through restraint. Shown in fig 6.23 and fig 6.24 are two pneumorph prototypes with stiff restraining layers and softer cavity structures.



fig 6.23 *Parallel cell*  $\times 00$ . Side view.

Composite material cast prototype with cavities and restraining layer.

Upper layer material: Two part platinum-cured silicone system (Platsil Gel 00, Mould Life)

Material softness: Shore OO hardness 30

Bottom restraining layer material: Two part addition cured silicone rubber (Addition Cure 13 Silicone Rubber, Tiranti)

Material softness: Shore A hardness 13 (Material coloured white for illustration purposes)

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<sup>174</sup> Ilievski, et al 2011, 1892.



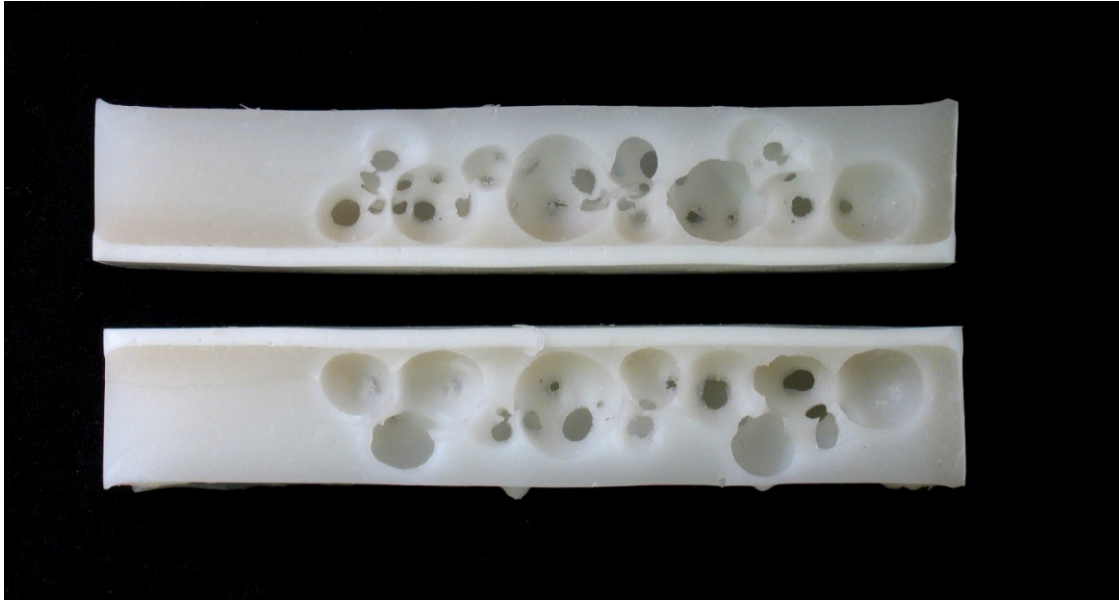


fig 6.24 *Spawn pneumorph Sp.00-30+A30*. Sectional view.

Composite material cast prototype with 'spawn' cavities and restraining layer.

Upper material: Two part platinum-cured silicone system (Platsil Gel 00, Mould Life)

Material softness: Shore OO hardness 30

Bottom restraining layer: Two part addition cured silicone rubber (Tiranti, T30 Silicone Rubber)

Material softness: Shore A hardness 30 (Material coloured white for illustration purposes)

### *Antagonist movement and elongation*

The cavity structures in the prototypes discussed above are arranged in single layers. Bending can only be achieved in one direction but no antagonist, or opposing, movement or elongation is possible. Antagonist bending can be facilitated by construction of two cavity layers either side of a restraining layer.

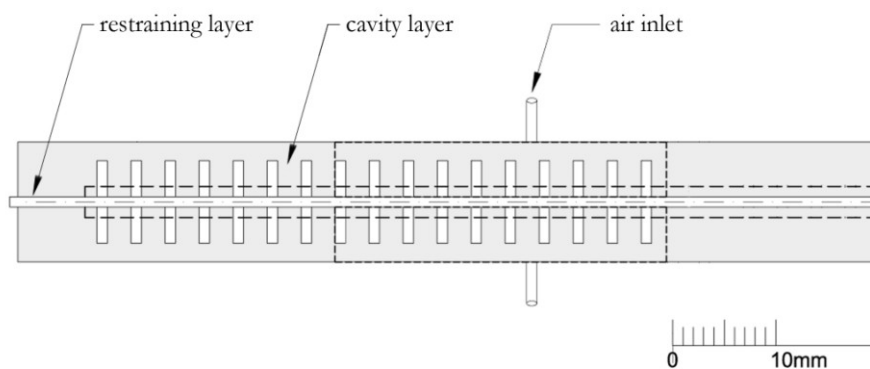


fig 6.25 Section drawing for parallel cell pneumorph.

The pneumorph features tow antagonist cavity layers separated by a restraining layer.

As shown in fig 6.26, upon pressurization of the upper layer this arrangement facilitates bending into downwards direction, while pressurization of the bottom layer facilitates bending into the antagonistic direction.

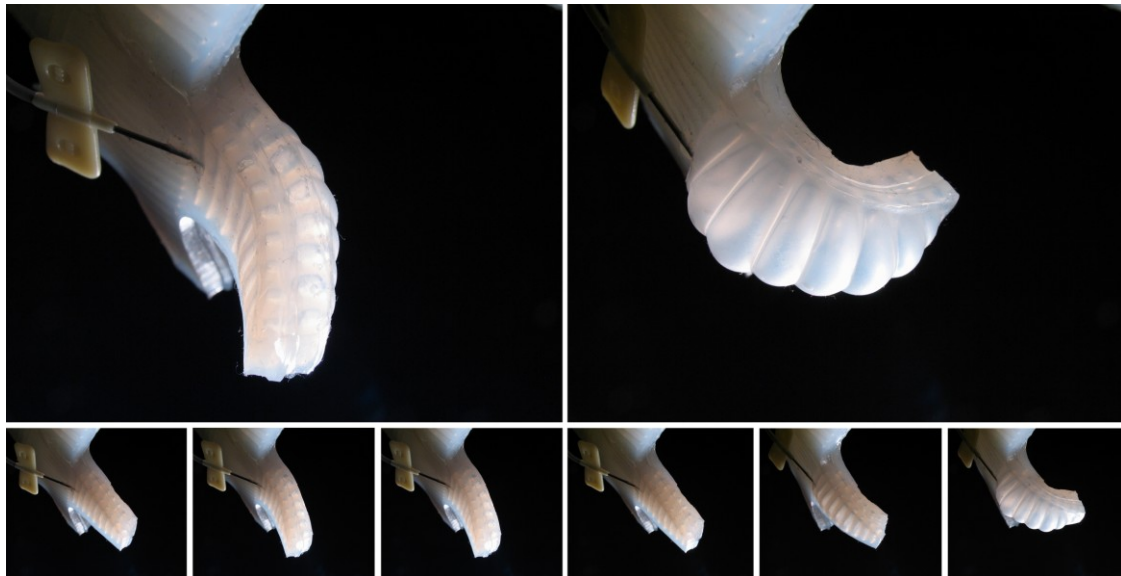


fig 6.26 Antagonist movements with a parallel cell pneumorph.

Alternating pressurization of cavity layers results in bending motion.

Composite material cast prototype with dual cavity layer separated by restraining layer.

Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Smooth-On)

Material softness: Shore OO hardness 10

Restraining layer: Two part condensation cured silicone rubber (Wacker Elastosil M4641 A/B, Canonbury Arts)

The curvature of composite pneumorphs thus can be changed from concave to convex upon actuation. When pressure is released the pneumorph returns to its default position. The bending action is most effective when only one layer is pressurized while the other remains passive (passive dynamics). However, when both layers are pressurized, as shown in fig 6.27 the resultant expansion of the cavities results in elongation of the pneumorph.



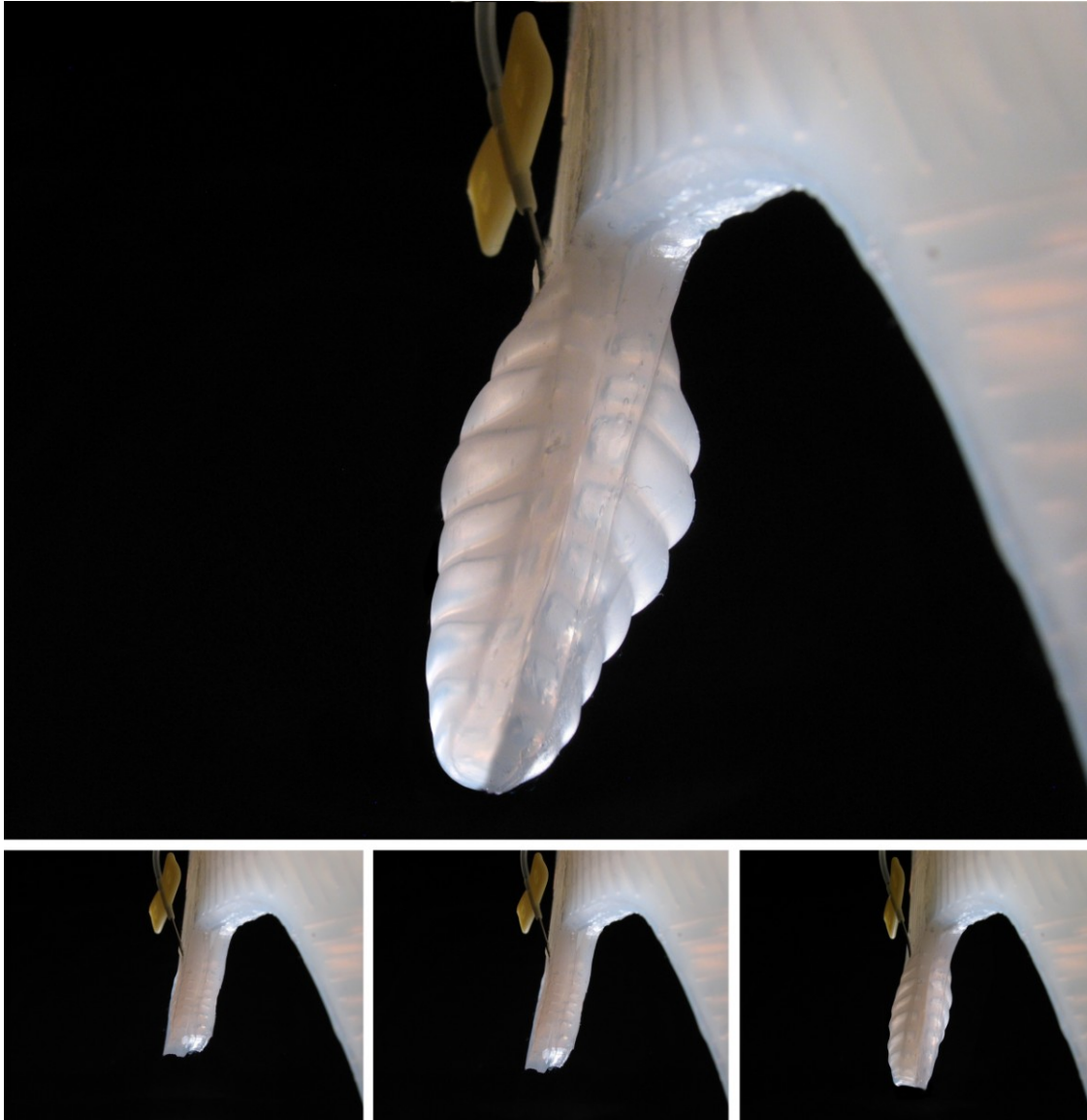


fig 6.27 Elongation movements with a parallel cell pneumorph.  
 Simultaneous pressurization of cavity layers results in elongation.  
 Material composition as pneumorph on fig. 6.26.

The spatial transformations of the series of prototypes discussed above suggest great potential for further research into providing spatial transformations through completely soft actuators. Freed from traditional mechanical concepts and stiff materiality pneumorphs can potentially unfold radically new spatial transformations of architectural machines and structures. The potential of pneumorphology for architectural design (and other disciplines) remains to be ascertained through further research and development. Following a brief excursus into hydromorphology (the variation of pneumorph

technology with liquids) further experimentation with pneumorphic transformations and their potential for architectural space-making will be discussed in the next section.

### Excursus: Hydromorphology and Microfluidics

A variation of the pneumorphology principle comes into effect when elastic structures are filled by liquid (hydraulics) rather than gas (pneumatics). I utilized hydraulic actuation technologies in the *Remote Prosthetics* (2005) and the *Soft Machine Dementia* (2004) projects.<sup>175</sup> While *Remote Prosthetics* experimented with the idea of distributed actuation through serial cardanic actuators, actuation in *Soft Machine Dementia* was facilitated by a single pulvinus joint. In light of the potential of pneumorphology further experimentation with distributed hydraulic technologies was a logical next step. The resulting strand presenting design and research opportunities could be called *hydromorphology*. This variation of the pneumorph approach offers the opportunity to use the actuating medium not only for motion induction, but also for introducing conditioning effects such as colour or temperature.

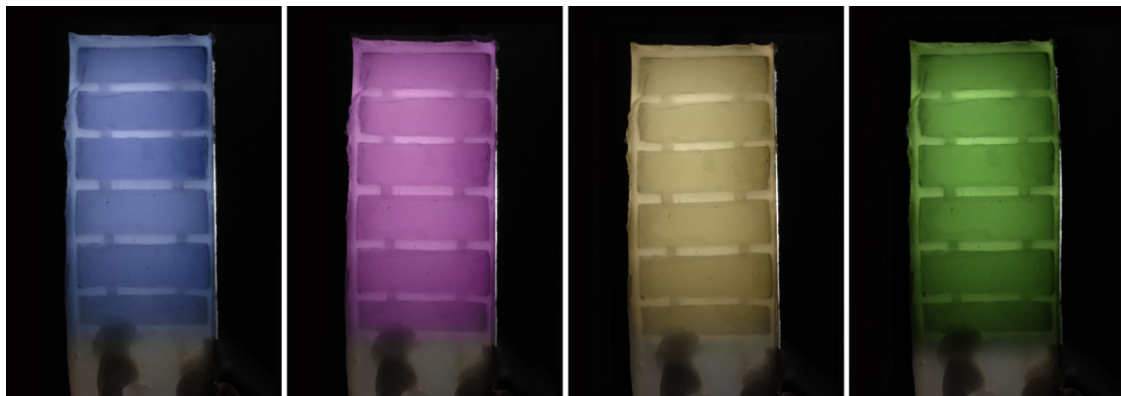


fig 6.28 Hydromorphs filled with liquids of varying colours.  
Photographs taken with backlight in order to enhance the colour effect.

Initial findings also show that the weight of the liquid and its fluid mechanical properties impose fundamentally different characteristics on the behaviour of the soft structure.<sup>176</sup>

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<sup>175</sup> Wihart 2005+2010.

<sup>176</sup> The combination of the incompressible nature of liquid and the elasticity of silicon or other elastomers leads to the situation that at some point the water outweighs the actuation potential and any added pressure would only lead to the expansion of the elastomer structure but not to any

For instance, the weight of liquid has a dramatic effect on the behaviour of soft machine as it tends to outweigh the machine itself.<sup>177</sup> These aspects have to be taken into consideration for structural design and motion planning. The hydromorph approach is versatile and, with an appropriate choice of materials, could be extended to applications that can facilitate higher loads.<sup>178</sup>

Hydraulics can also be employed for microfluidic liquid distribution within elastomer layers through a network of channels *without* actuation goals. Whitesides' group has fitted the Multigait Robot with an additional elastic layer that can facilitate change to colour or patterns of its appearance.<sup>179</sup> As Stephen A. Morin et al explain in their paper 'Camouflage and Display for Soft Machines,' 'simple microfluidic networks can change the colour, contrast, pattern, apparent shape, luminescence, and surface temperature of soft machines for camouflage and display' imitating 'functions, although not the anatomies, of colour-changing animals.'<sup>180</sup>

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additional motion induction. Consequently, the shore hardness and elasticity modulus values of the elastomer have to be adjusted in accordance to the force required for the desired motion induction. It is assumed that the actuation layer and microfluidic layers of the Whitesides' Multigait Robot are kept separate because of these incompatibility issues.

<sup>177</sup> This somewhat paradoxical circumstance has been taken advantage of by harnessing the swelling and weight distribution of the liquid. In contrast, EPNs are actuated with gas (air) and in an experimental set-up the weight of air has no influence on actuation.

<sup>178</sup> Ilievski 2011, 1894.

<sup>179</sup> Morin et al 2012, 828.

<sup>180</sup> Morin et al 2012, 828. Whitesides' Group research on the Multigait Robot is DARPA funded (award number W911NF-08-1-0143, fund \$605,926.00, focussing its purpose on military usability. See document 12-F-1039\_2010-DARPA-Funding-List, p 23 at [www.dod.gov](http://www.dod.gov); accessed 04/02/2013.

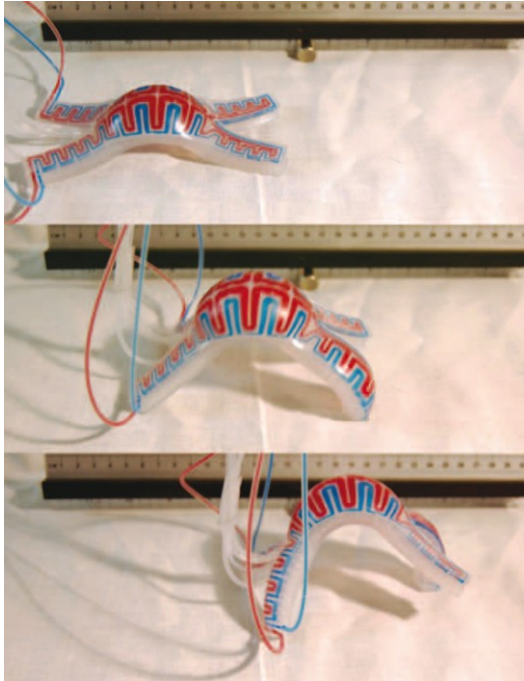


fig 6.29 Stephen A. Morin et al. *Multigait soft robot* with microfluidic network layer. 2012.

Hydraulic actuation is amenable to designs that require greater force (than pneumporphs), or incompressible modules, or density (of soft mechanic architectural modules or structural elements). However, it is likely that the materials required will have to be composites of elastic and strain limiting materials. Similar venues into conceptions of structure, materials and systems on a system level symbiosis have been explored in the design and construction of architectural components, structures and tectonics by architects such as Tom Wiscombe, who specializes in speculative design of composite structures and architectures. Projects such as *Batwing* (2008) or *Squished! Prototype 1.0* (2013) are based on manifold geometries that envision the incorporation of structural, mechanical and system behaviours on building scales.<sup>181</sup> Although these speculative projects are not meant to transform dynamically, they demonstrate a shift towards integrative and co-constituting design sensibilities.

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<sup>181</sup> [http://www.tomwiscombe.com/project\\_22.html](http://www.tomwiscombe.com/project_22.html), accessed 28/11/2013.

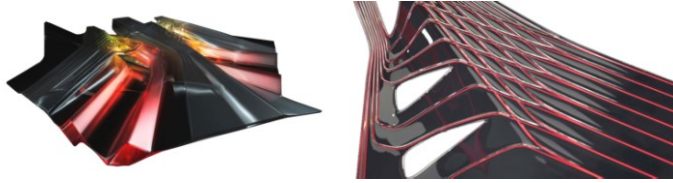


fig 6.30 Tom Wiscombe. *Batwing*. 2008.

This project is a study for an integrated solution for a facade or flooring truss that functions structurally as well as carrying services.



fig 6.31 Tom Wiscombe. *Squished! Prototype 1.0*. 2013

The project questions 'conventional 20th century assembly logic was in favour of polymer-based meta-assemblies produced through squishing, sedimenting, embedding and inlaying.'

[End of Excursus]

Research into architectural appropriation of elastic and transformable pneumatic technologies, which I term pneumorphology, has also been undertaken by Dino Rossi at the Institute for Architecture and Sustainable Building Technologies at the Faculty of Architecture at ETH Zürich as part the *Adaptive Solar Facade Project*.<sup>182</sup>

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<sup>182</sup> <http://adaptivesystemslab.blogspot.co.uk>; accessed 28/03/2013.

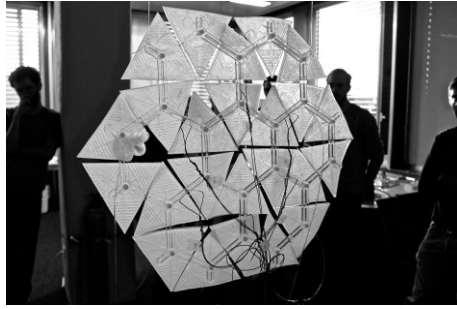


fig 6.32 Dino Rossi. *Soft Robotic Façade prototype*. 2013.

The project has been developed at the Institute for Architecture and Sustainable Building Technologies at ETH Zürich. The facade prototype is composed of multiple triangular shaped pneumorph fields which are arranged in a hexagonal pattern and can be bent into one direction by pressurisation.

Although Rossi's project suggests new ways for dynamic calibration of façades it also restrains the experimental potential of pneumorphs for experimentation with their space-making capacities. Instead of conceiving of pneumorphs as prototypes that invite research into industrial applications, which undoubtedly have great potential as shown by Rossi, I have developed pneumorphs as part of my research into the softening of machines. As such I do not want to restrict pneumorphs to be what they literally are (prototypes) or could be (components) but I prefer to allow them to become scale-less soft machines that can be imbued with an imaginary potential for envisioning a inhabitable and capacitated , yet compliant architecture [c7 Embodied architecture]. As my own research will show in the following section the transformational potential of pneumorphs can range from the complete inversion of surfaces to multiple bending action or undulations and convulsions of envelope structures, which successively inspire a critique of traditional tectonic conceptions in favour of more dynamic and embodied ones.

My research into elastically transformable, composite and embedded systems indicates that at larger architectural scales pneumorphology, as well as hydromorphology and microfluidics, can offer possibilities for dynamic and integrated building conditioning and spatial transformations. Pressurisation media such as gas or fluids can be used not only as carriers for temperature, humidity or colour but also for actuation. Effects might include modifiable visual appearance in combination with integrated facilitation of heating or cooling. Due to these capacities, hydromorphs and pneumorphs (fitted with microfluidic networks) can also be considered as enabling studies for the conception of dynamic architectural walls, envelopes or furniture.

### s3 | Morphodynamic transformations and space-making

Pneumorphic precursors in architecture – Space-making with pneumorphs – Morphodynamic potential for interiority and exteriority.

Pneumorphology presents an opportunity for creating transformable spatial structures. More complex pneumorph designs involving multiple fields, phased and choreographed actuation of various parts can potentially facilitate spatially complex transformations. The transformational potential of soft machine components that are mechanically unrestrained but elastic and fully flexible can be exploited for creation of spatially diversifying structures. The space-making potential of multi-cell transformable pneumatic structures was recognised by architectural pneumatic pioneer Frei Otto in the 1970s but has not been pursued at this point in time.<sup>183</sup> Some experiments undertaken by Fisher, Conolly (*Dynamat*, 1969-71) and Wellesley-Miller (*Binary Cell System* and *Air-Coil System*, 1971) explored the capacity of these systems to adapt and react to different environmental factors, expanding the lineage of architectural inflatables with aspects of dynamic and transformable pneumatics.

‘Morphodynamic transformation’ is a neologism that attempts to describe how a particular artefact is changed through its dynamic transformation. This may apply in more general terms to soft transformable projects such as Rossi’s *Soft robotic facade* or in more specific terms to pneumorphic precursors by Otto, Fisher, Conolly and Wellesley-Miller and my pneumorphic studies *Nemone Stuehl!* or *Robe* (2013), discussed in this section. The term addresses specific dynamic conditions associated with the process of transformation of soft-bodied structures. Similar to the way fluids are described in theories of fluid dynamics but applied in this case to the soft structures of soft machines, morphodynamics is proposed as a conceptual framework for the study of dynamic transformation of soft structures. Morphodynamic experiments have shown that pneumorph morphologies can be transformed by differential actuation from a concave structure suggesting conditions of

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<sup>183</sup> Van Schoor in Bubner 1975 [IL 12], 82.

*interiority* to a convex structure suggesting *exteriority*. However, these antagonistic conceptions are being dissolved through the dynamic variation of space by a single morphodynamic artefact.

## **Pneumorphic precursors in architecture**

Pneumatic membrane structures and pneumorphs are both inflatable structures, but while in pneumatic structures *tension-resistant* material is distributed in a single layer of uniform thickness (membranes), *elastic* material in pneumorphs is distributed volumetrically.

### *Frei Otto's pneumatic motion systems and soft systems*

Research at Frei Otto's Institut für Leichte Flächentragwerke (IL) in Stuttgart was undertaken under the overarching hypothesis that 'the pneu is the essential formation principle in living nature.'<sup>184</sup> While most of the pneu research of the IL understood pneu structures as an effective way to generate minimal structure by comparative biological research and experimentation, some outputs also demonstrated the transformational potentials of pneumos. Most remarkably, the extensive studies of biological pneu-structures undertaken at the IL also revealed the potential for adaptation of muscular hydrostat systems for transformable architectural systems.<sup>185</sup> These research undertakings into biological structures capable of motion induction through pressurization informed studies on convertible pneumos<sup>186</sup> and pneumatic motion systems.<sup>187</sup> This research underscores that architectural pneumorph structures can also be explained by a bio-analogy to muscular hydrostats. Thus, the *hydrostatic* principle could be formulated as a *pneumostatic* principle as the basic condition that stabilizes or animates pneumorphic structures.<sup>188</sup>

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<sup>184</sup> Otto 1977 [IL 9], 5.

<sup>185</sup> Hydroskeletal bracings, as described in IL 9. Gutmann in Otto 1976 [IL 9], 176.

<sup>186</sup> Bubner 1975 [IL 12], 14-27 + 76-79.

<sup>187</sup> Otto 1977 [IL 9], 42 + 112-114.

<sup>188</sup> It can be hypothesized that instead of being restrained in their dynamical range of transformation by non-elastic membranes, 'classical' pneu structures could be animated using the elastic pneumorph approach.



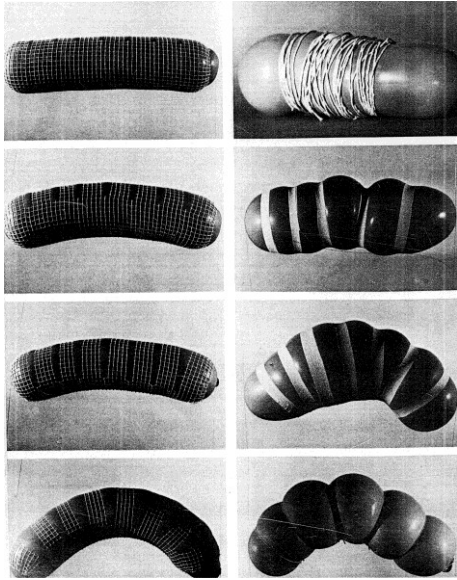


fig 6.33 Frei Otto. Motion sequence of pneu studies with tension bands. 1979

The application of ‘adhesive strips or cords’ restrain the rubber balloon from finding its ideal spherical shape and force it to become a tube. ‘If the bands do not lie parallel to one another but instead at an angle, the tube curves’ (Otto 1979 [IL 19], 38).

With reference to ‘soft systems’ Otto discusses the ‘hydroskeleton of catapillars, worms and other animals.’<sup>189</sup> Otto elsewhere relates to the shape-changing potential of pneus: ‘The ability of a pneu to change its shape depends on the material properties of the envelope. Its elasticity, thickness, and internal structure are of particular influence.’<sup>190</sup> Studies with rubber pneus fitted with ‘unstressed, tension-resistant bands’ approximate the hydrostatic principle using the pneu principle. With these experiments Otto demonstrated the potential of elastic pneus to facilitate motion induction through shape change.<sup>191</sup>

### *Fisher, Conolly and Wellesley-Miller: third generation pneumatics*

Extensive studies with convertible membrane structures have been undertaken at the IL. According to Berthold van Schoor ‘multicell pneumatic convertible structures with a high adaptability and ability to react to different environmental factors are also called the “third

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<sup>189</sup> Otto 1976 [IL 9], 260.

<sup>190</sup> Otto 1979 [IL 19], 24.

<sup>191</sup> Unfortunately, Otto did only continue the studies with elastic pneus for form-finding purposes (Otto 1979 [IL 19], 40-41).

generation” of pneumatic structures.<sup>192</sup> However, van Schoor points out that the IL did not pursue transformable multi-cell structures because they believed the motility of these systems would not fit into the realm of building technology – pointing to the more experimental approaches of Simon Conolly and Mark Fisher.<sup>193</sup> Conolly and Fisher – influenced by Archigram, but unwilling to confine their technical curiosity to ‘paper architecture’ – set up Air Structures Design (ASD) in 1969.<sup>194</sup> Emerging from this collaboration was a series of transformable pneumatic structures. Fisher and Conolly constructed *Dynamat* (1969-71), a full-size panel of a multi-cell transformable pneu.<sup>195</sup> The structure consisted of a series of inflatable cells, which could be selectively expanded or deflated. The movements were controlled by pneumatic pressure, which were generated by vacuum cleaners and a series of valves which opened or closed in pre-programmed sequences.<sup>196</sup>

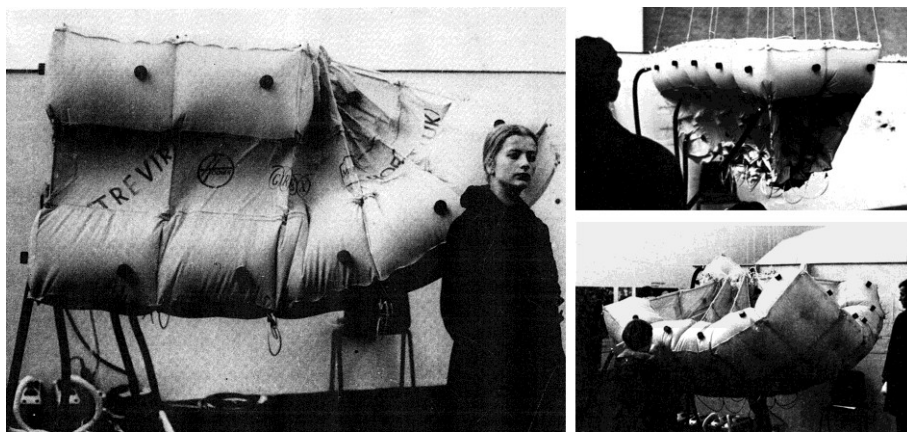


fig 6.34 Mark Fisher and Simon Conolly. *Dynamat*. 1971.  
Full-scale prototype panel in different configurations.

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<sup>192</sup> Van Schoor in Bubner 1975 [IL 12], 26. Similar developments have been made by J.M. Davies, University at Los Angeles and K. Hubbell at Yale School of Architecture. See Conolly 1972.

<sup>193</sup> Van Schoor in Bubner 1975 [IL 12], 82.

<sup>194</sup> Holding 2000, 24.

<sup>195</sup> Conolly 1972, Section 3.1, Holding 2000, 22 and Bubner 1975 [IL 12], 20. The project was exhibited the Biennale in Paris in 1969 and at the ‘Deubau’, the German International Building Exhibition in 1971 in Essen. The project was also features in the article ‘Pneu Moves’ Architectural Design 1972 and presented at the Delft ‘Pneumatic Structures Symposium’ 1972.

<sup>196</sup> Conolly 1972, Section 3.1.

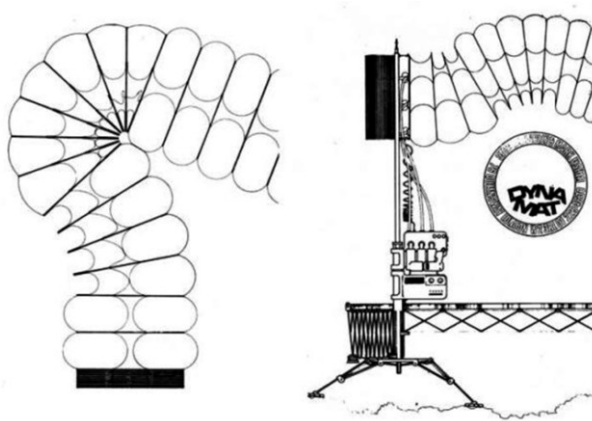


fig 6.35 Drawing showing multi-cell arrangement for dynamic transformation by means of de- or inflation of cells.

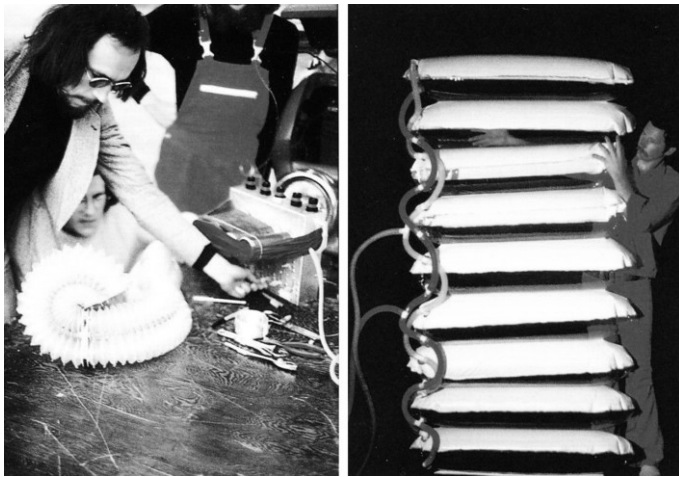


fig 6.36 Preliminary transformational studies with multi-cell inflatables.

Fisher developed the *Dynamat* ideas further in the *Responsive Dwelling Project* (1973-75) where 'the division between the technics of the building and the organic world of the inhabitation became blurred.'<sup>197</sup> The *Responsive Dwelling Project* attempted to bring together structural, cybernetic and environmental systems into a single matrix.<sup>198</sup>

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<sup>197</sup> Fisher quoted in Holding 2000, 25.

<sup>198</sup> Holding 2000, 25.



fig 6.37 Mark Fisher. *Responsive Dwelling Project*. 1973-75.

A project, similar in composition to the *Dynamat*, the ‘binary-cell system’ was developed by Sean R. Wellesley-Miller at Massachusetts Institute of Technology in 1971, supported by Negroponte.<sup>199</sup> The prototype suggested transformable wall-like structures.<sup>200</sup> However, in contrast to the *Dynamat* the central layer is continuous and un-pressurized. For actuation the structure’s top or bottom layer can be inflated in alternating pattern, thus generating morphodynamic transformation. Another typology developed by Wellesley-Miller was an inflatable parallel cell structure, which he referred to as the ‘air-coil-system.’<sup>201</sup> Van Schoor observes that such ‘[d]ual-layered pipe systems ... make possible the bending and rolling up of the total structure.’<sup>202</sup> Frei Otto discussed similar systems in *Convertible roofs* (1972 [IL 5]).

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<sup>199</sup> Wellesley-Miller 1972, Section 3.8, SWM-22.

<sup>200</sup> Wellesley-Miller 1972, Section 3.8; and Van Schoor in Bubner 1975 [IL 12], 20.

<sup>201</sup> Van Schoor 1975 [IL 12], 16.

<sup>202</sup> Van Schoor 1975 [IL 12], 16.

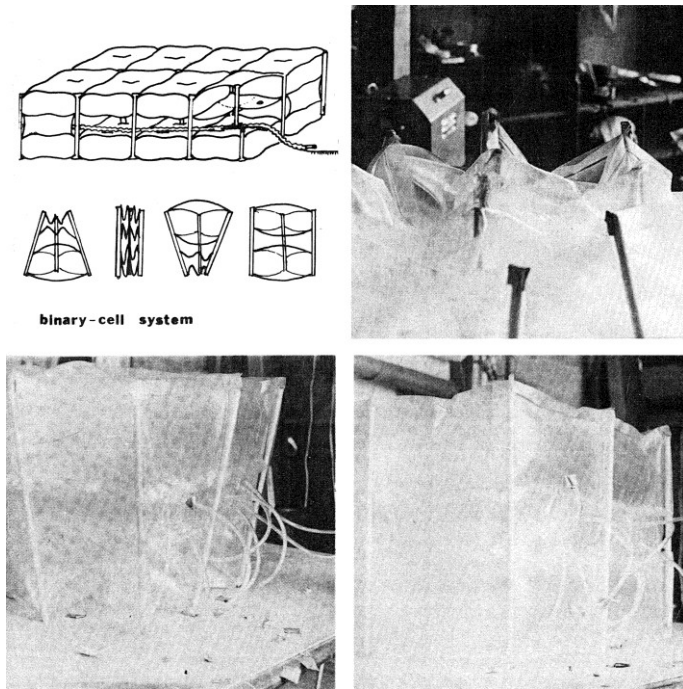


fig 6.38 Sean R. Wellesley-Miller. Prototype of 'air-coil-system'. 1971.

Approximately 100 PVC tubes – closed at both ends and with a diameter of 100mm – were welded together and to both sides of a membrane.<sup>203</sup>

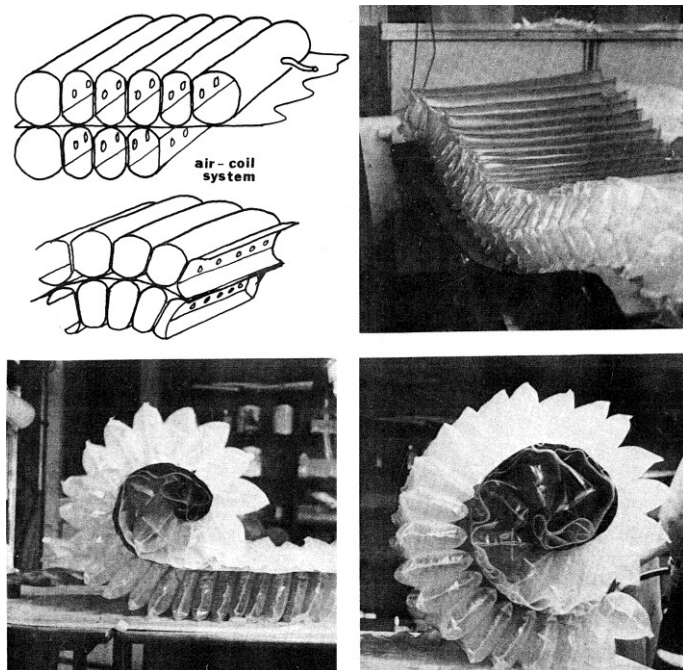


fig 6.39 Sean R. Wellesley-Miller. Prototype of 'binary cell system'. 1971.

Approximately 100 PVC tubes – closed at both ends and with a diameter of 100mm – were welded together and to both sides of a membrane.<sup>204</sup>

<sup>203</sup> Van Schoor 1975 [IL 12], 16.

Wellesley-Miller explains the working principle of his cellular pneumatic system:

As soon as the tubes are inflated, they try to expand to their completely spherical diameter, each tube pushing against its neighbour. If the lower layer has not been inflated, or has a lower pressure than the upper layer, the total structure arches bottom-wards. The same applies to the upper layer, correspondingly. The total vault is a function of tube diameter, layout, and pressure. Rigidity is determined by flexibility of the membrane, contact area, and absolute pressure; the sum of the movement, by the sum of the inflation.<sup>205</sup>

One might believe that the similarity between the pneumatic systems discussed above might be a deceptive coincidence, were it not for their special capacities where many different approaches demonstrate their transformational potential. In this case the coincidence hypothesis becomes the least probable option. While soft robotics has employed these strategies in smaller scales for locomotion architectural experimentation has focused on animation of structures suggesting the dynamisation of tectonic primitives such as wall, roof and ceiling structures. Convertible pneumatic structures as proposed by Conolly, Fisher, Wellesley-Miller and others are based on non-elastic membranes. Despite using the same actuation design concepts, the essential difference of pneumorphs lies in the use of elastic polymer materials, thus facilitating passive dynamics and intrinsic compliance, and generally more intensive morphodynamic transformations.<sup>206</sup>

## **Space-making with pneumorphs**

Transformable pneumatic structures offer unique potential for dynamically ordering space. Because pneumorphs are activated by internal force application, frames or

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<sup>204</sup> Van Schoor 1975 [IL 12], 16.

<sup>205</sup> Van Schoor 1975 [IL 12], 20 and Wellesley-Miller 1972, Section 3.8. SWM 14-18.

<sup>206</sup> There is also a difference in maintenance between non-elastic membranes and polymer-based structures; the former can be easily cleaned while the latter tends to hold dust due to its soft and sometimes tacky surface properties.

mechanical systems do not restrict motility.<sup>207</sup> The pneumatic cavities are integrally embedded and due to the elasticity of the pneumorph allow can facilitate highly flexible movements with a high number of degrees freedom (DOFs), capability of elongation, antagonist movement, variable and controllable stiffness, high dexterity, and fine manipulation capabilities. I have incorporated these pneumorphic transformation capacities into two pneumorph projects *Nemone Stuelp!* (2013) and *Robe* (2013), which will be discussed next in more detail. Multiple versions have been tested. The aim of these experiments was to investigate the space-making capacities of pneumorphs through prototype testing.

### *Nemone Stuelp!*

For *Nemone stuelp!* (2013) experiment a pneumorph has been constructed that features a Reuleaux triangle-shaped plan geometry and antagonist pneumorphs cavities either side of a restraining layer. The three actuators of each pneumorph layer can be actuated independently.

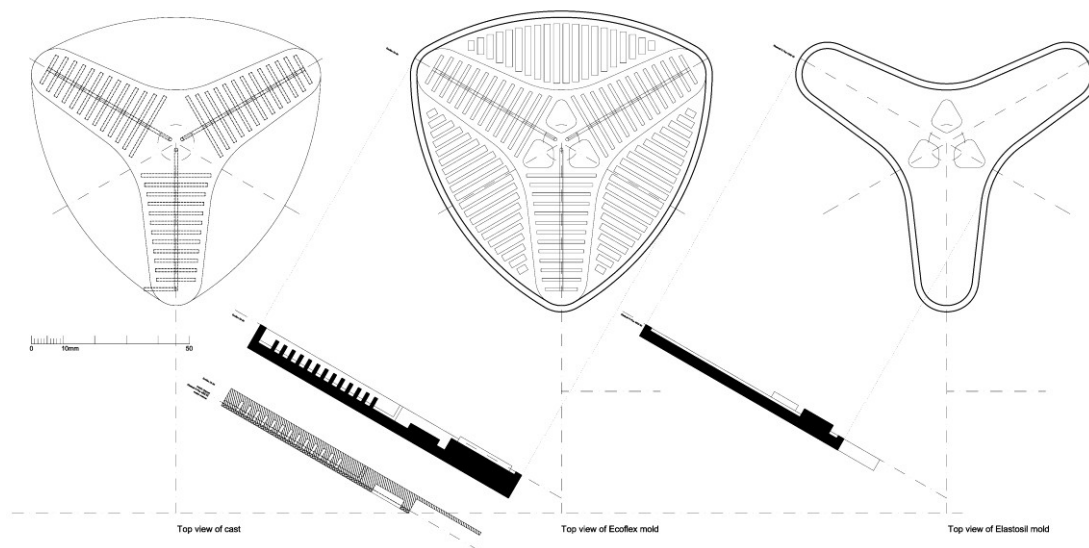


fig 6.40 Construction drawing for *Nemone stuelp!* with parallel cell cavities.

The drawing shows the Reuleaux triangle-shaped cast and the two mould components required for the construction process.

<sup>207</sup> Internal force application in pneumorph is generated by external force application, either manually through use of pumps or by use of electrical pumps, control boards etc. The next stages of pneumorph R&D comprise the integral incorporation of pneumatic pumps, conduits and valves.

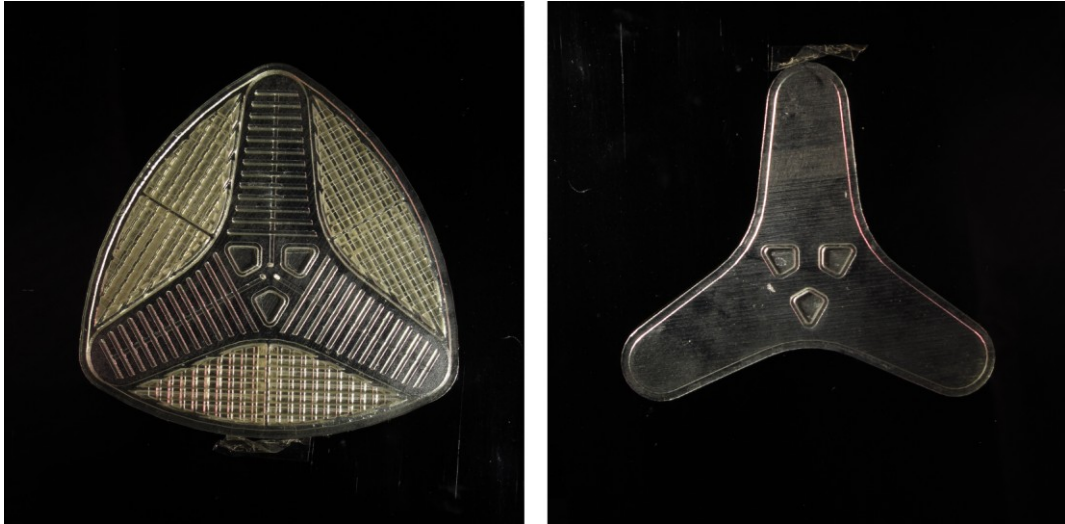


fig 6.41 Photographs of 3D printed moulds.  
The moulds have been built with *VeroClear* on an *Objet Connex 500* printer.

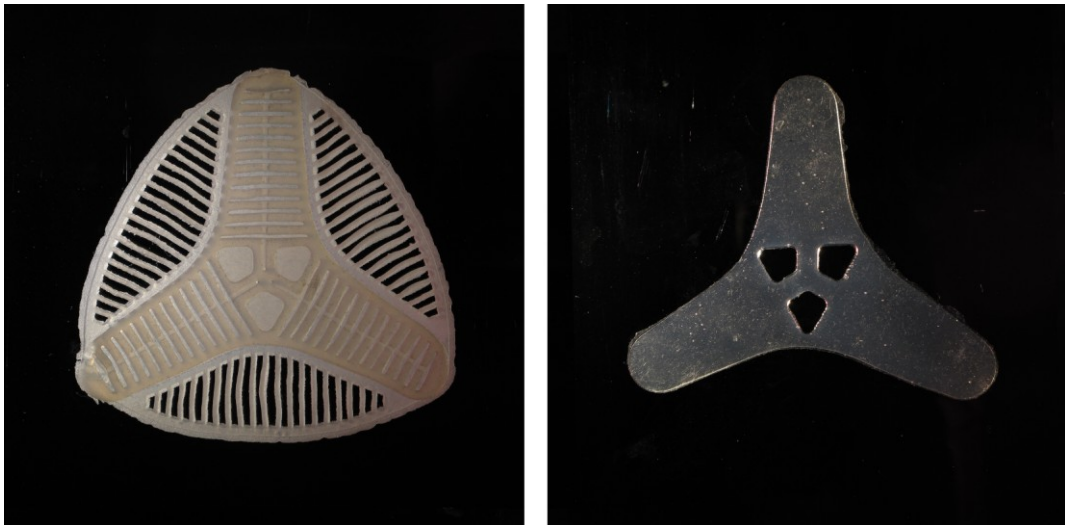


fig 6.42 Photographs of cast silicone components.  
Composite material cast pneumorph with multiple field phased actuation capable of bending in antagonist directions.

Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Smooth-On)

Material softness: Shore OO hardness 10

Restraining layer: Two part condensation cured silicone rubber (Wacker Elastosil M4641 A/B, Canonbury Arts)

Material softness: Shore A hardness 43



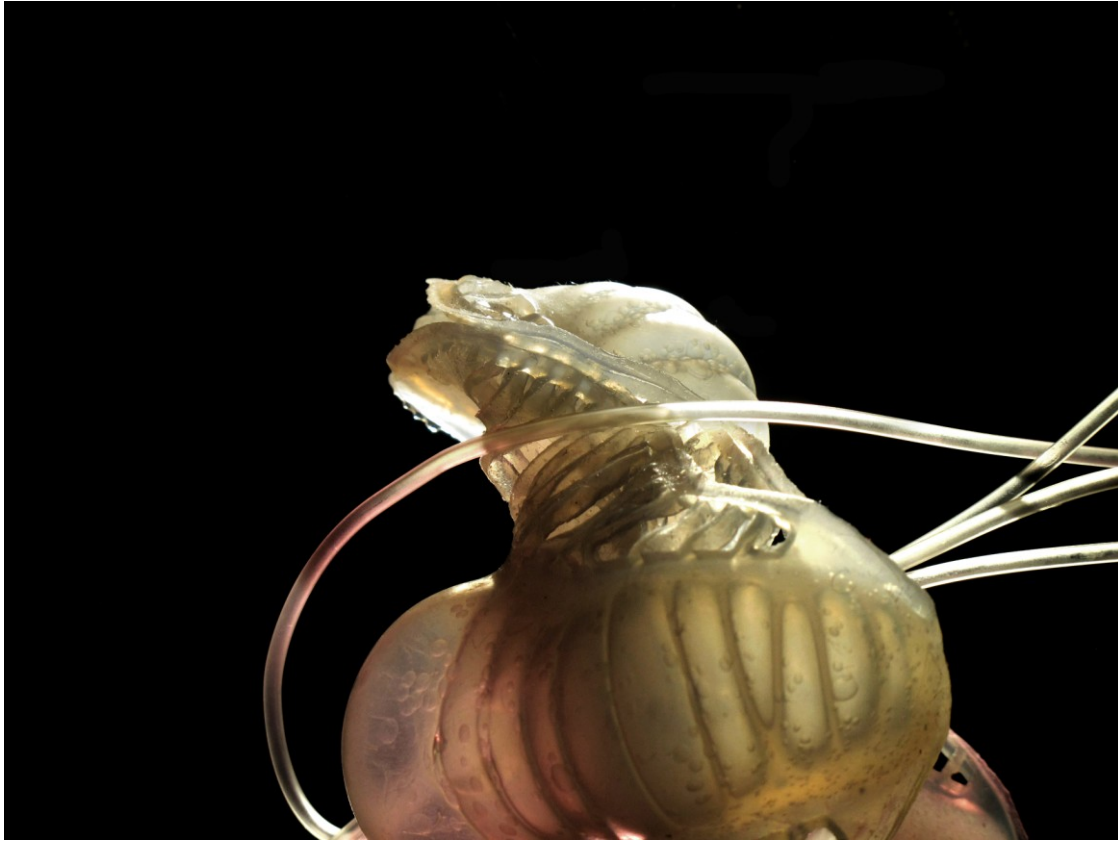


fig 7.43 Still shot of spatial transformation under varying levels of pressurization.

Composite material cast pneumorph capable of elongation, antagonist movement and transformation.

Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Smooth-On)

Material softness: Shore OO hardness 10

Material: Two part addition cured silicone rubber (Addition Cure 13 Silicone Rubber, Tiranti)

Material softness: Shore A hardness 13

## *Robe*

The *Robe* (2013) experiment investigates the technical requirements for morphodynamic transformation induced by inflation of multiple pneumorph cavity structures. The experiment derives its name from a long garment, the robe, examining how the robe is transformed in the process of dressing / undressing. The incentive for this experiment was to research how structure and actuation of the *Robe* pneumorph have to be devised in order to facilitate intensive morphodynamic transformations. The first step in the design process was finding a suitable default configuration that would be the middle ground between its two maximum inflation scenarios. This experiment assumes the default position of the pneumorph in a pressurized condition, as shown in fig 7.44.

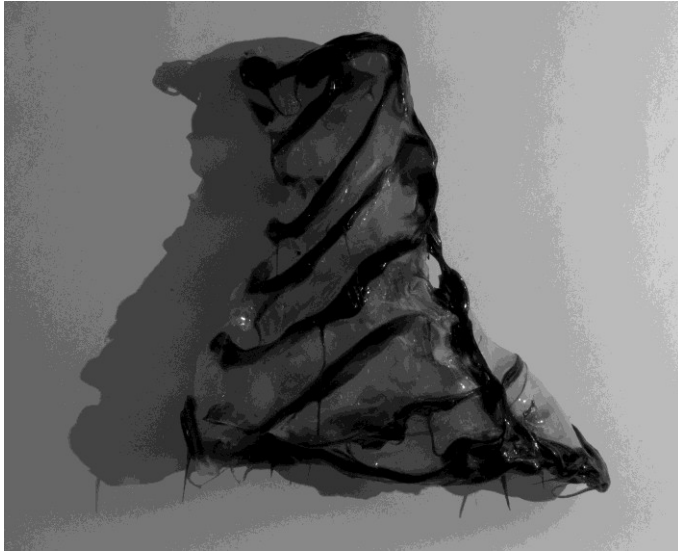


fig 6.44 Silicone sketch.

In contrast to its predecessor, which has been developed assuming a flat base shape – the *Robe* pneumorph has been developed based on a multi-curved geometry that allows for intensive alternations between concave and convex conditions.

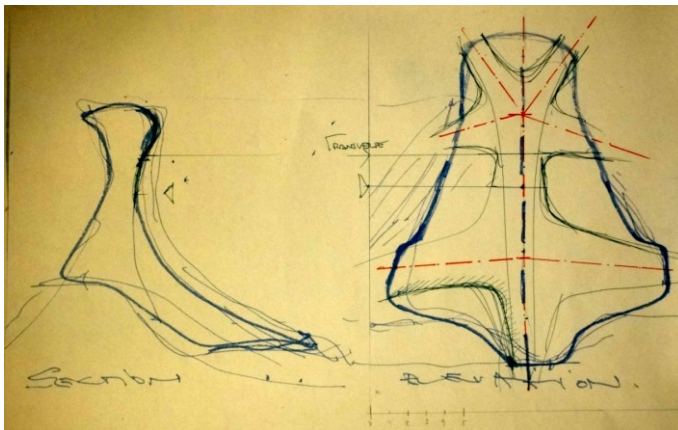


fig 6.45 Preliminary drawing establishing actuation design outline and bending directions.

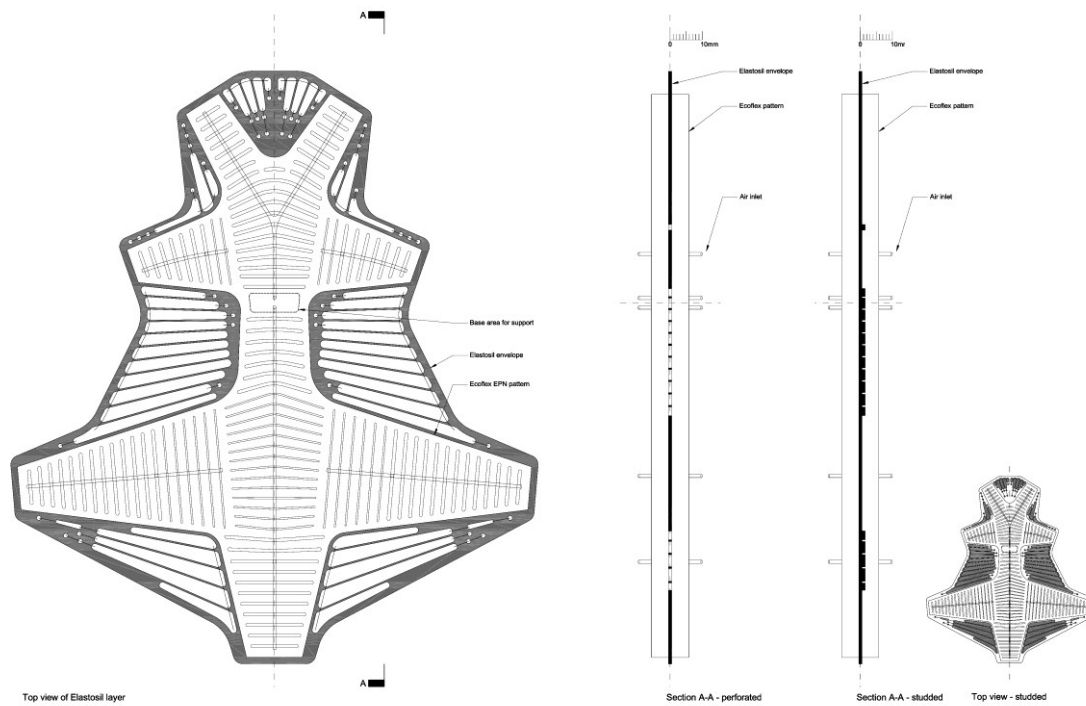


fig 6.46 Construction drawing for silicone robe layer

The drawing shows the outline of the pneumorph cavity fields in combination with the silicone robe layer

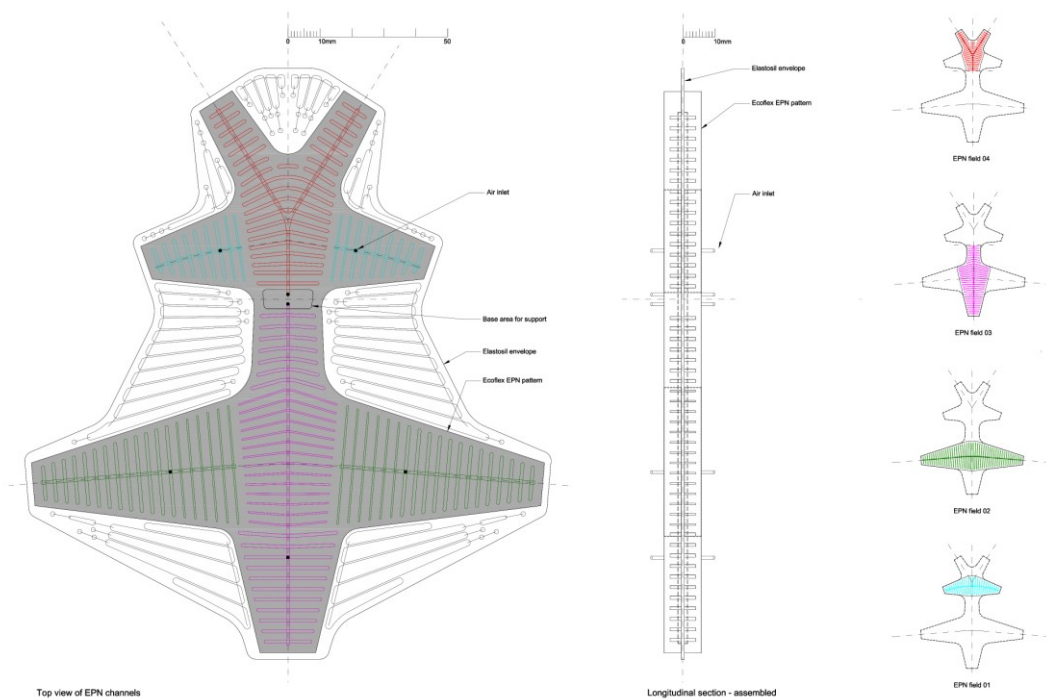


fig 6.47 Construction drawing for pneumorph cavity fields

The drawing shows the outline of the pneumorph cavity fields in combination with the silicone 'robe.'

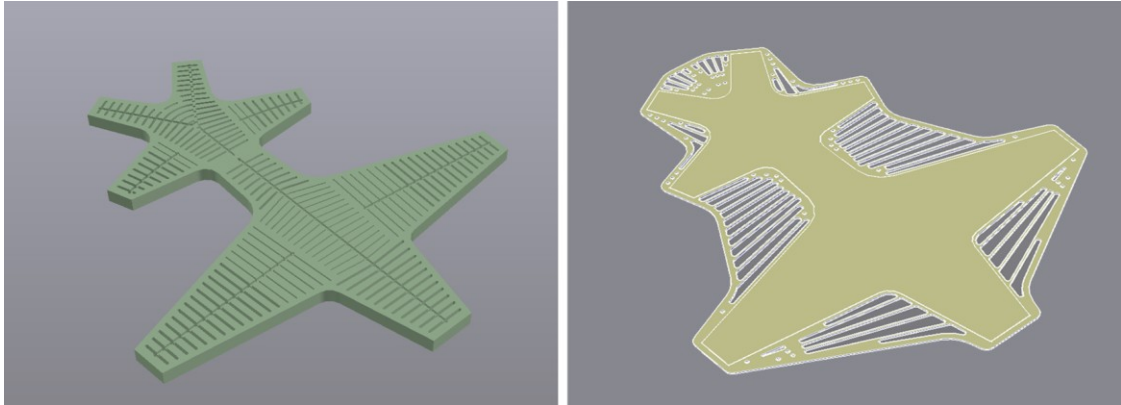


fig 6.48 Renderings of silicone cast components.  
The moulds have been built with *VeroClear* on an *Objet Connex 500* printer.

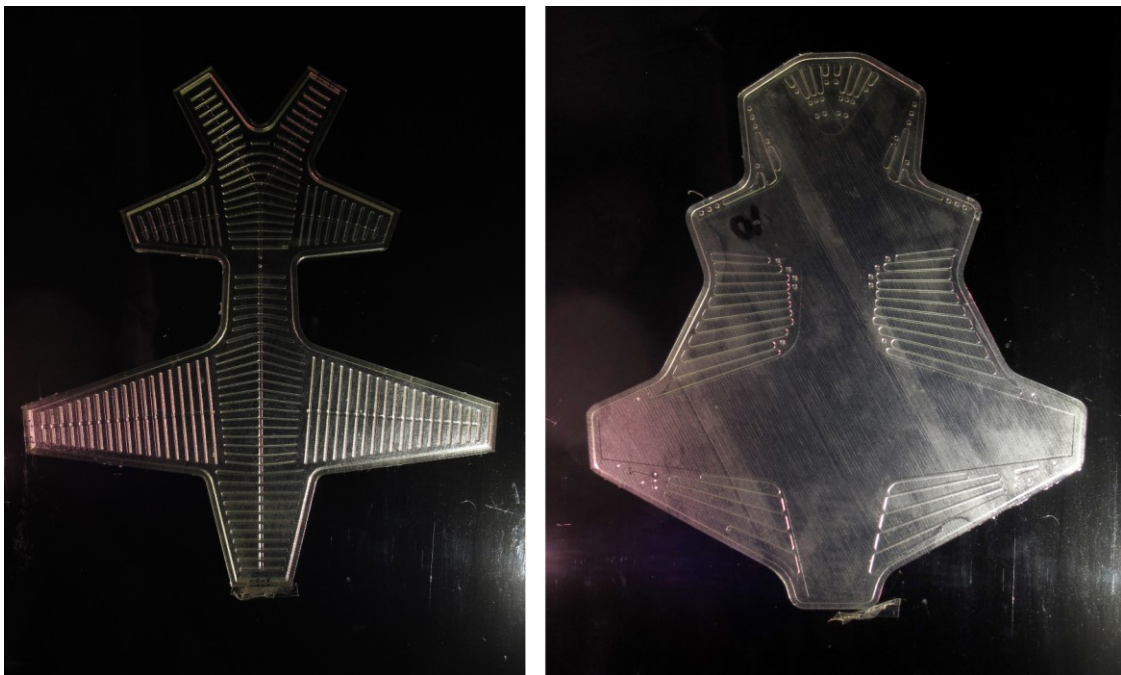


fig 6.49 Photographs of 3D printed moulds.  
The moulds have been built with *VeroClear* on an *Objet Connex 500* printer.





fig 6.50 Photograph of *Robe* silicone composite no. 10-43 D30 at atmospheric pressure.

Composite material cast pneumorph with multiple field phased actuation

Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Smooth-On)

Material softness: Shore OO hardness 10

Restraining layer: Nylon mesh (Denier 30) inlay in two part addition cured silicone rubber (Wacker Elastasil M4641 A/B, Canonbury Arts).

Material softness: Shore A hardness 43

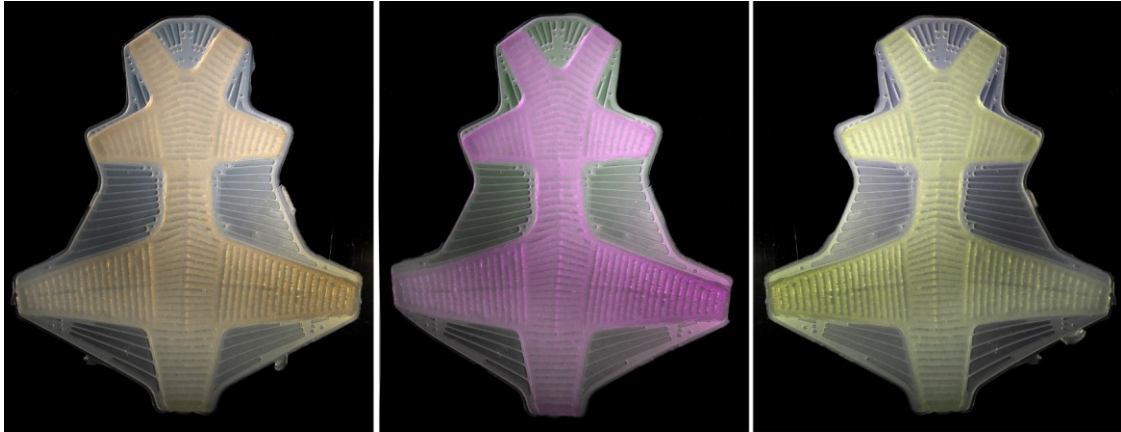


fig 6.51 *Robe* silicone composite no. 10-43 with colour variations.

Actuation layer material: Two part platinum-cured silicone system (Ecoflex 00-10, Smooth-On)

Material softness: Shore OO hardness 10

Restraining layer: Two part addition cured silicone rubber (Wacker Elastosil M4641 A/B, Canonbury Arts)

Material softness: Shore A hardness 43

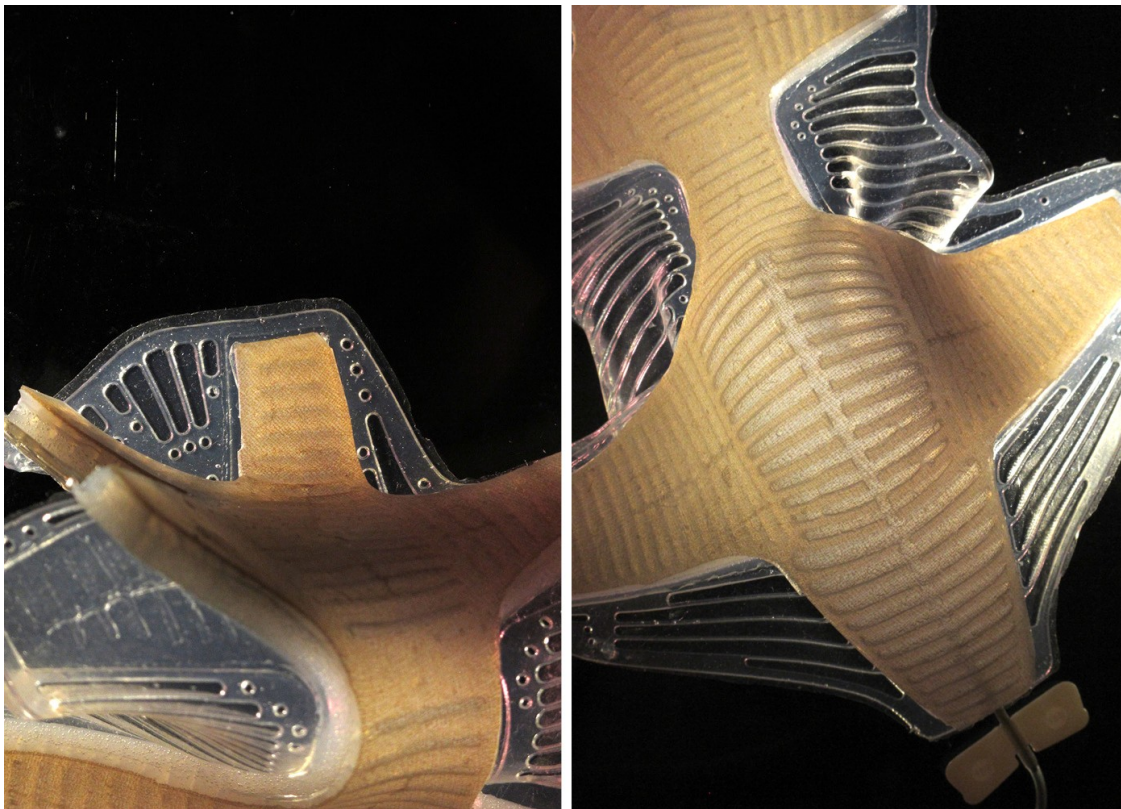


fig 6.52 *Robe*. 2013. Still shots of morphodynamic transformations of *Robe* 10-43 D30.



## Morphodynamic potential for interiority and exteriority

The application of pneumorphology for actuation of architectural soft machine structures is not limited to facilitation of movement alone. The pneumorph experiments suggest the potential to form spatial conditions with alternating characteristics. As can be shown by simultaneous actuation of all cavity segments of *Nemone Stuehl*!, the pneumorph can transform from a convex to a concave shape. By inflation of its outer cavities, the pneumorph can form a concave-shaped enclosure. Alternatively, by inflation of its inner (in this case antagonist) cavities the structure unfolds and forms a convex-shaped semi-sphere. The spatial aspects of the unfolding process are termed ‘stuelping’ and will be discussed in detail in chapter 7.

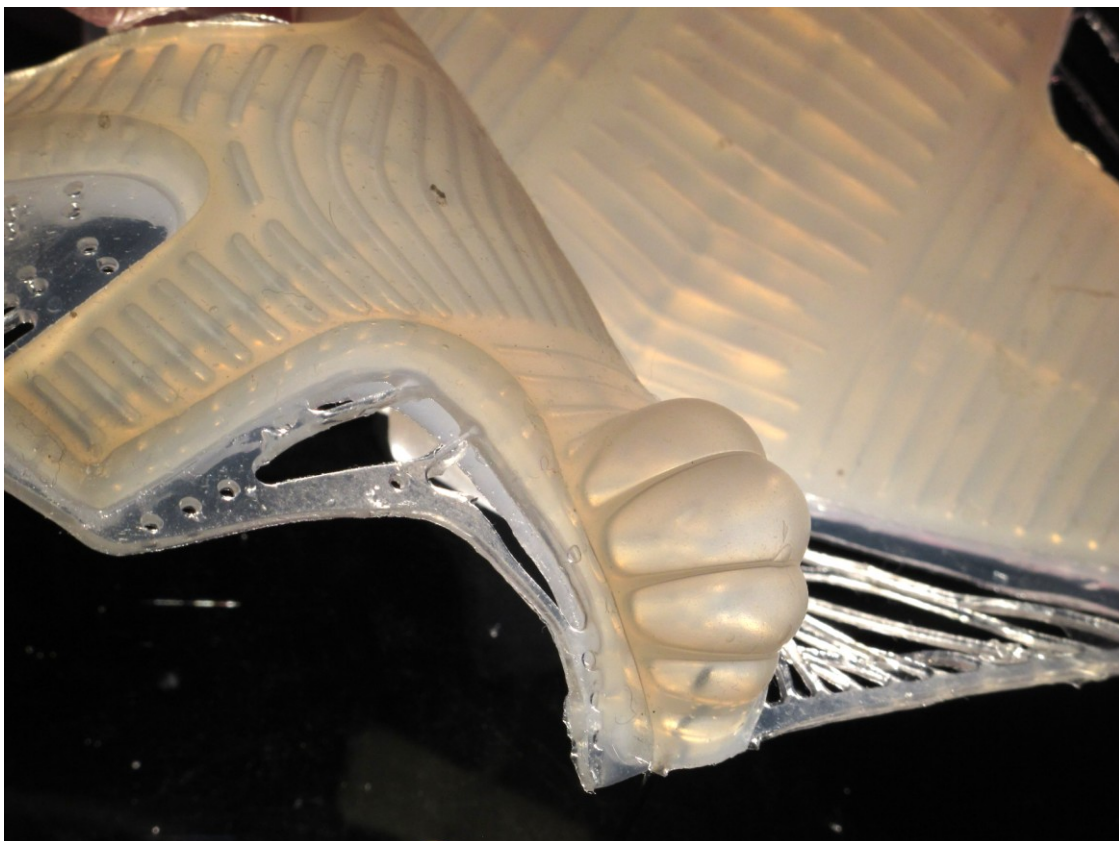


fig 6.53 *Robe*. 2013.

Pneumorph morphologies can be transformed by differential actuation from a concave structure suggesting conditions of interiority to a convex structure suggesting exteriority. Activation sequence with pressurization of all three cavity fields of inner layer – creating interiority.

More intense transformation, such as the complete inversion of surfaces, can be achieved by combination of multiple bending actions or undulation of enveloping structures. The space-making potential of the pneumorph technology lies in offering the possibility for articulating many different spatial conditions through a single artefact. Combinations and juxtaposition of space-making pneumorphs with one another or with morpho-static structures can create entirely new possibilities for conceptualizing space-making in architectural design. The potential of this pneumorphology technology for architecture will be discussed in the next chapter by applying to it discussions of topology, spatiality and morphology.

## c6 | Conclusion

By bio-inspired synthetization of actuation systems found in soft-bodied animals soft roboticists have created novel methodologies for the mechanical characterization of soft robots and machines. The aim of soft robotics differs from that of architectural soft machine design in that research in the former tends to focus on autonomous systems capable of locomotion, while soft machines are used for experiments about conditions of architecture.<sup>208</sup> In the context of this research soft robotic actuation concepts have been applied to ‘sited’ – or to speak in terms of robotics – ‘tethered’ machines, thus focusing on the transference of soft robotic enabling technologies into the realm of architectural design and construction. Other characteristics, such as compliance and passive dynamics are equally transferrable and relevant, offering possibilities for architecture to reflect its human-centred purposes through softer conceptions of machines. Soft machines are rapidly increasing in functionality *because* they are made of soft materials, leaving behind mechanical limitations imposed by stiff structures and joints.<sup>209</sup> The complete entanglement of soft material properties with pneumatic or hydraulic actuation mechanisms has stimulated the development of novel solutions and experimental set-ups.

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<sup>208</sup> Many soft robotic systems are currently developed in order to recreate locomotion systems found in the natural world, such as the rolling action of caterpillars (GoQBot), the soft and flexible movements of an octopus arm (Octopus project), or fish locomotion (FILOSE). However, it must be noted that these systems are not truly autonomous at this stage as the control and actuation units are external of the robot.

<sup>209</sup> Crespi et al 2005, pp 163-175.



Based on these premises, pneumorphology has been proposed as framework for the development of pneumatically actuated, dynamically transformable structures. Experiments based on the hypothesis that really soft machines enable the development of new pathways for architectural design have departed from 'hard' type mechanical set-ups in architectural machines. Truly flexible and elastic spaces articulated through morphodynamic transformation of pneumorph artefacts offer new methods of architectural space-making, potentially inviting transgression of static notions of tectonics and space.

The development of sophisticated soft robots and androids presents a new set of questions to architecture, combining the anthropocentric argument of architecture with that of machines. Cedric Price, in his introductory lecture to the International Symposium on Pneumatic Structures in Delft, 1972, pointed out that the implementation of innovative technologies such as pneumatics hinges on social acceptance, technical feasibility and last but not least with approval by building authorities.<sup>210</sup> I wonder if he has ever contemplated a *Really Soft Fun Palace*? However paradoxical this may seem, but as soft machines and robots assimilate human mannerisms in behaviour and corporeality, they might in turn stimulate architecture to appreciate that what is human by mediating more intimate possibilities of interaction between human beings and their architecture.

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<sup>210</sup> Price 1972.

## c7 | Embodied architecture

Morphodynamic primitives – The liminal space of stuepeling – Designing the embodied

... maybe concepts like ‘room,’ ‘door’ and ‘window’ are anachronisms.

Nicholas Negroponte<sup>211</sup>

Openness permits exchange, ensures movement, prevents saturation in possession or consumption ... My lips are not opposed to generation.

They keep the passage open ...

Luce Irigaray<sup>212</sup>

### Introduction

Enabling technologies such as pneumorphology can stimulate discussions about architectural environments capable of responding to human inhabitation through morphodynamic change. Because of a space-making potential that reaches beyond static strictures and architectural denominations (ceiling, floor, wall, façade), morphodynamic transformations motivate the articulation of an ontology that incorporates the intrinsic properties of soft and elastic transformation, compliance and passive dynamics. Changes of topology by envelopes and structures that can be turned inside out or given another direction through the bending and flexing of their surfaces are fundamentally affecting architecture’s classical inside/ outside duality and necessitate an examination of liminal and fleeting relations between their interior and exterior spaces. However, by making architecture active and physically morphodynamic, the conceptual shift is not only about overcoming the axiom of physical permanence of architecture, but also about incorporating the intrinsic binding of movement with control (and in its more

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<sup>211</sup> Negroponte 1975, 145.

<sup>212</sup> Irigaray 1992, 63, 65, 66. Also Rendell, Jane. ‘Doing it, (Un)Doing it, (Over)doing it Yourself: Rhetorics of Architectural Abuse’, in Hill 1998, 229–246.

sophisticated manifestations self-awareness or even intelligence).<sup>213</sup> Consequently the ontology of architecture's constituent components cannot be exclusively topological or functional, but should attempt to promote integrative, inclusive and co-constituting approaches.<sup>214</sup> But once the potential of really soft machines is fully appreciated the idea of architecture softened by machines can look to the body, not as a model of geometric order, but as a model of sensitivity, intelligence and relational capacity. At this point, we must be reminded of Maria Luisa Palumbo's proposition of a daring frontier where 'new relations between the body and architecture aspire towards a *sensitisation* of space, namely architecture's aspiration to *be embodied* ...'<sup>215</sup> Palumbo explains (with reference to Negroponte's work on soft architecture machines) that in order to translate the corporeality of the living body into '*corporeal* architecture,'<sup>216</sup> the information paradigm must be changed from the mechanical and computational logic of the *abstract* machine<sup>217</sup> into a logic ... that underlies the physical or *corporeal* basis of living systems.<sup>218</sup> But while Palumbo effectively suggests that the concept of embodiment should be tied to the human being inasmuch as it should be tied to the body of architecture, she does not suggest executive strategies or enabling technologies.

In robotics, the concept of embodiment was adapted during a major paradigm shift in the 1980s towards acknowledgment of the inseparable connections between the mind and its body.<sup>219</sup> This concept is used to characterize the role of the body's integrated and co-constituting architecture in intelligent behavior, and builds on the seminal work of roboticist Rodney Brooks.<sup>220</sup> Applied to machines, embodiment implies that they can understand and control their own actions as they can learn, unlearn and accommodate

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<sup>213</sup> Evidence in research of biological mental development and in Artificial Intelligence (AI) and robotics suggests that an active body is indispensable for acquisition of artificial intelligence. See Pfeifer et al 2007.

<sup>214</sup> Architects renowned for favouring design strategies on inclusive approaches include Ben van Berkel with UN Studio and Tom Wiscombe.

<sup>215</sup> Palumbo 2000, 6.

<sup>216</sup> Palumbo 2000, 66 [italics in original]. Marcos Cruz calls this concept 'corpology' (2014).

<sup>217</sup> Here it must be assumed that Palumbo does not allude to Deleuze's concept of the *abstract machine* but rather uses the term to describe a theoretical model of a computer hardware or software system.

<sup>218</sup> Palumbo 2006, 6 [italics in original].

<sup>219</sup> Pfeifer and Fumiya 2004; Pfeifer et al. 2012, 84.

<sup>220</sup> Brooks 1999; especially 'A robust layered control system for a mobile robot,' pp 3-27. Originally published in 1986 in *IEEE Journal of Robotics and Automation*. RA-2 April 1986. pp 14-23.

behaviour and environmental changes. As surging interest in robotics and artificial intelligence has led to appreciating the role of the body in shaping the (artificial) mind, the embodied architecture approach proposes to conceive of architecture as if it had a body. By adapting the embodied approach, architectural design can develop notions of reciprocal conditioning of its constituent systems, materials, morphologies and behaviours.<sup>221</sup>

### *Chapter overview*

In the first two sections of this chapter I discuss spatial and topological modalities of the architectural, morphodynamic body in ‘embodiment’ in order to provide a conceptual platform for speculations about potential design strategies for embodied architecture in section 3. Section 1 proposes a non-exclusive theoretical basis, starting out with basic components including *epithelial envelopes* and *stuelps*, *edges*, *apertures* and *folds* and the transient, morpho-topological constrictions created by their reconfiguration, so-called *migrating thresholds*. Section 2 looks at stuelping as an intensive process, juxtaposing my own experiments with projects that ‘stuelp but don’t know it yet’ in order to discuss the conditions and theoretical ramifications of their topological and spatial transformations. Among other projects and studies, I discuss three of my own, *Broomz* (2013), *Oasis 8 – Compliance House I* (2013-ongoing) and *Laryngeal Mesomachine* (2009-ongoing). These studies take on the scale of building projects in order to speculate about embodiment in architecture. While they are not soft machines themselves, these studies are conceived as embodied architecture with the intention of researching certain of their conditions with soft machines. These experiments would then address issues such as space-making (morphodynamic transformation), pneumorphic and hydromorphic network structuration in combination with morphodynamic design, distributed sensory networks and morphological computing, self-model, learning and control. The completion of the projects lies beyond the scope of this thesis, but is anticipated through proposed design strategies discussed in section 3.

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<sup>221</sup> Some proposed concepts, methods and enabling technologies are discussed in c7. s3 Designing the embodied.

# s1 | Morphodynamic primitives

Epithelial envelopes – Stuelps – Edges, apertures, folds – Migrating thresholds

Pneumorph experiments with the pneumorph projects *Nemone stuelp!* (2013) and *Robe* (2013) have demonstrated potential for spatially intense transformations. Enabling technologies such as pneumorphology impose their own structural and systemic requirements on the structures in which they are embedded. Traditional approaches based on tectonic orders consisting of static elements such as walls, floors, ceilings – and the openings formed within, such as doors and windows – are fixed to assumptions of architectural permanence, stasis and rigidity.<sup>222</sup> *Soft tectonics* – when architecture is conceived as soft and pliable – require an ontological approach based on categories of being and their relations that incorporates rather than excludes the intrinsic properties of morphodynamics, compliance and passive dynamics. This section proposes as spatial primitives *epithelial envelopes* and *stuelps*, *edges*, *apertures* and *folds* and the transient, morpho-topological constrictions created by their reconfiguration, so-called *migrating thresholds*.

By proposing a framework of morphodynamic primitives, methods of morphology<sup>223</sup> are combined with concepts of spatial primitives used in some neuroscientific theories of form cognition.<sup>224</sup> Despite my effort to give these primitives a name, they cannot be tied down to a fixed identity as they (envelopes, stuelps, edges) might undulate, shift and

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<sup>222</sup> Schmarsow 1894, Giedion 1941, Arnheim 1977.

<sup>223</sup> The type of morphology referred to is the study of form and structural features in the biological sciences. See Wainright, C. Peter. 'Innovation and diversity in functional morphology' in Laubichler, Manfred D. and Maienschein, Jane (ed.) 2010. *Form and Function in Developmental Evolution*. Cambridge: Cambridge University Press. pp 132-152.

<sup>224</sup> Here I refer to George Lakoff's embodied mind philosophy. Lakoff maintains that 'spatial concepts can be decomposed into universal cognitive primitives' and combinations of primitives are called 'image schema.' Lakoff continues with an example, considering the word *into* in a sentence like "Harry walked through the kitchen into the dining room." The 'meaning of *into* consists of two primitives: a CONTAINER – that is, a bounded region in space – and a PATH, with a SOURCE and a GOAL.' Lakoff explains that the 'image schema for *into* consists of a PATH schema and a CONTAINER schema, where the SOURCE of the PATH is in the EXTERIOR of the CONTAINER and the GOAL of the PATH is inside it.' See Lakoff, George. 'The Neuroscience of Form in Art' in Turner, Mark (ed.) 2006. *The Artful Mind: cognitive science and the riddle of human creativity*. Oxford: Oxford University Press. pp 153-154.

transform. Others generated through these motions appear and disappear (apertures, folds, thresholds) as spatial palimpsests.

## Epithelial Envelopes

Soft, flexible and pliable enveloping structures with morphodynamic capacities can create conditions ranging from openness to closedness, including phased conditions in between. But such envelopes should not be contemplated as discrete, homogenous surfaces. Rather they have ‘flesh’<sup>225</sup> and thickness, incorporating systems and behaviours through hybrid design. More embodied approaches could accommodate neo-physiological functions and capacities, ranging from sensors and fluidic fields to pneumorph fields and structures. Here Teyssot’s notion of ‘epithelial envelopes’ can provide a better understanding through bio-inspiration.<sup>226</sup> Epithelial tissue is the layer that lines internal cavities throughout the body. Embedded in epithelial tissue are also glands that secrete mucus and other fluids. Other functions of epithelial tissue include absorption, protection, trans-cellular transport and detection of sensation.<sup>227</sup> Similar to tissue in biological bodies, epithelial envelopes can be envisioned fitted with embedded structures for building conditioning, sensing or other anthropocentric interfaces.

### *Wulschter*

Conceived as a preparatory study for epithelial envelopes (and as a sub-project of *Broomz*, where the embedded conditioning of envelopes was studied) the *Wulschter* (2013) envelope is populated by a diverse range of systems including hybrid structural members and air support channels, compressed air containers, spawn type pneumorph fields [c6. s2] and embedded fluidic networks [c6. s2]. The name *Wulschter* is a derivative of the German word ‘wulst’ [germ: vulst/ f. (Noun)], which means bulge or ridge. Giving the word an active voice by the addition of -er, it is thought to express that it is an active ‘bulger.’

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<sup>225</sup> Here I allude to Marcos Cruz’s terminology ‘architectural flesh,’ through which he critiques ‘skin’ as one of architecture’s most fundamental metaphors in favour of ‘a thick embodied flesh’ (2007).

Also see Cruz 2014.

<sup>226</sup> Teyssot 2005, 72-84.

<sup>227</sup> Marieb 1995, 103-104.

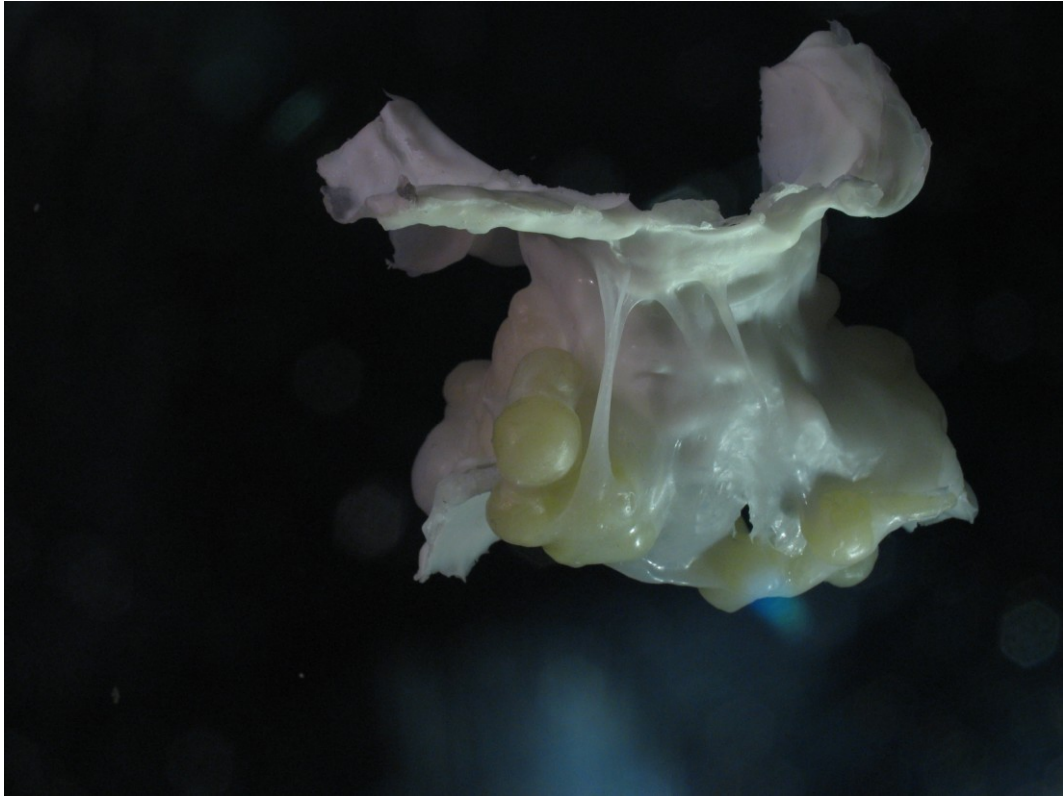


fig 7.01 *Wulschter*. Silicone cast study for embodied envelope.



fig 7.02 *Wulschter*. Detailed view.

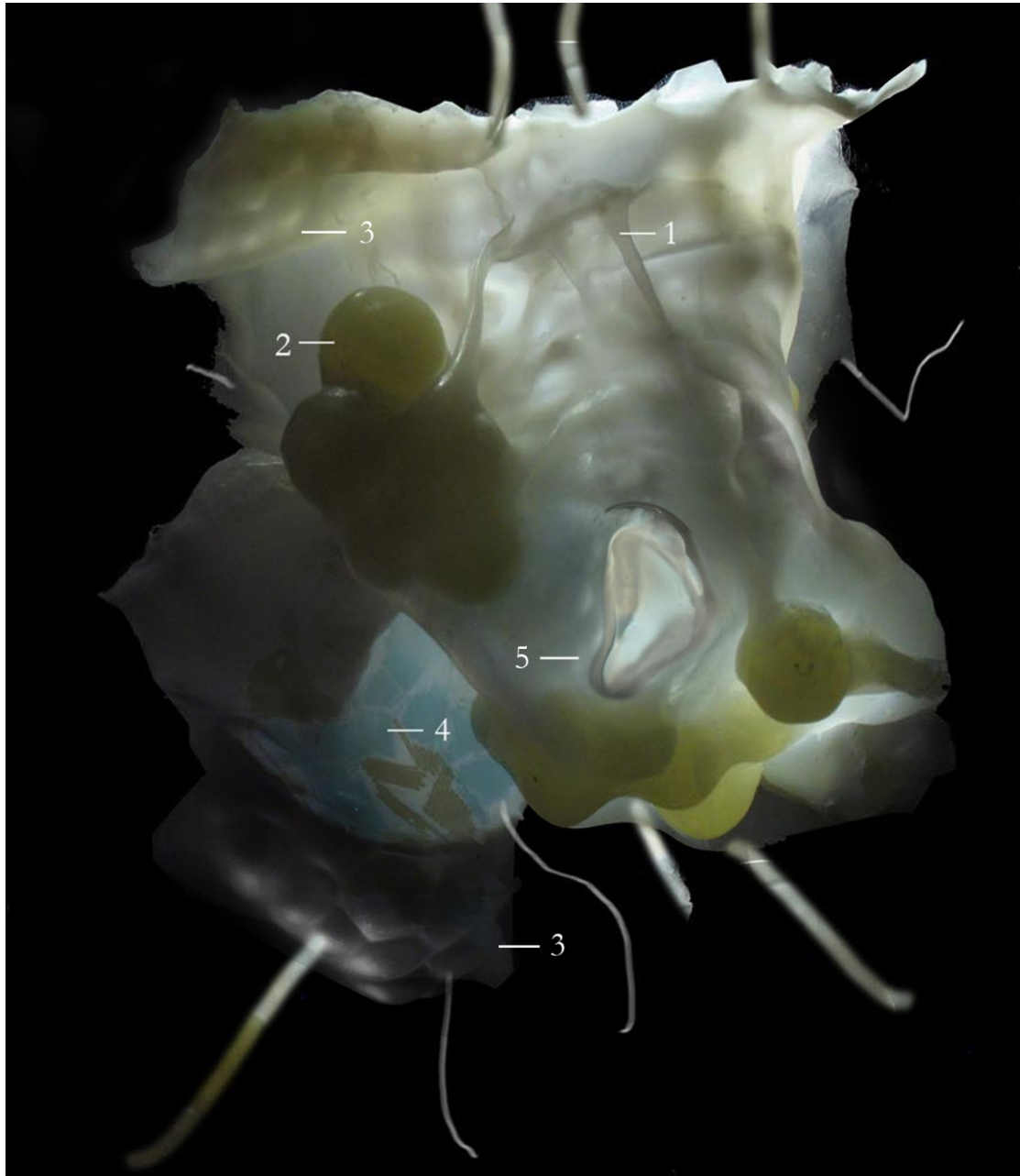


fig 7.03 Photomontage of facade mock-up with embedded systems.

(1) Composite structural bracing and air conduits, (2) compressed air containers, (3) spawn type pneumorph fields, (4) embedded fluidic network and (5) aperture.

The topological openness is of critical importance for soft mechanics of spatial transformations, and for enabling spatial qualities and their inhabitational offerings to transform, migrate and flux. The agenda for designing 'topologically open' architecture is also advocated by Tom Wiscombe in his text 'Objects inside Objects:'



If architecture is thought of in terms of objects rather than subdivisions, it follows that building massing, interior spaces, surface articulation, and ground can all be dealt with as things-in-themselves rather than as contingencies of one another. The idea of a ‘figure-in-a-sack’ is one part of this concept, where a building is not an envelope subdivided by floors and walls, but rather an organization of nested objects. By placing distinct objects into an elastic sack, mysterious formal inflections and complex interior spaces are produced. This problem forces the consideration of silhouette and shape at the scale of the interior objects as well as at the scale of buildings...<sup>228</sup>

Wiscombe’s ‘things-in-themselves’ and ‘distinct objects in elastic sacks’ imply that they are not closed containers but topologically open, in order to allow morphodynamic variations of their relations with other primitives.

## Stuelps

Fleeting moments of envelopes in morphodynamic transition depend on their topological pre-conditions but can involve complete inversions of their surfaces. This operation can be best emulated by taking a sock or a pocket as a model and turning it inside out. Subsequent experimentation and research point towards a constructive revision of architecture’s fundamental inside / outside duality while warranting appropriate description of the process itself. However, there is no specific term that would allow fixing its meaning for the denomination of these processes. Therefore I have created the neologism *stuelping*, which is a combination of the German verb ‘stülpen’ and its English present participle.<sup>229</sup>

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<sup>228</sup> Wiscombe, Tom. ‘Objects inside Objects’ on [www.wiscombe.com](http://www.wiscombe.com); accessed 03/04/2013.

<sup>229</sup> The German verb ‘stülpen’ is written with umlaut u. This is changed to ‘stuelping’ written with ‘ue’ to better accommodate usage in the English language.

*Stuelping* is a neologism that describes the process of turning something inside out.

**Stuelping**, the spatio-dynamic operation of [germ.: stülpen/ 'ʃtʏlpn/ tr. V. *etw.* auf od. *über etw.* (Akk.) ~: pull/ put sth. on to *or* over sth.; turn the/ one's pockets inside out]; n. stulp; v. stuelpen (past tense: gestuelpt); adj. gestuelpt.<sup>230</sup>

### *The topologically open sock*

In order to better understand the morphodynamics of stuelping I have conducted preliminary transformational experiments involving the inversion of surfaces by stuelping a silicone sock.



fig 7.04 *Maria's Sock*. 2012.

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<sup>230</sup> This speculative dictionary entry has been composed by the author. It is a hybrid of German and English meanings.

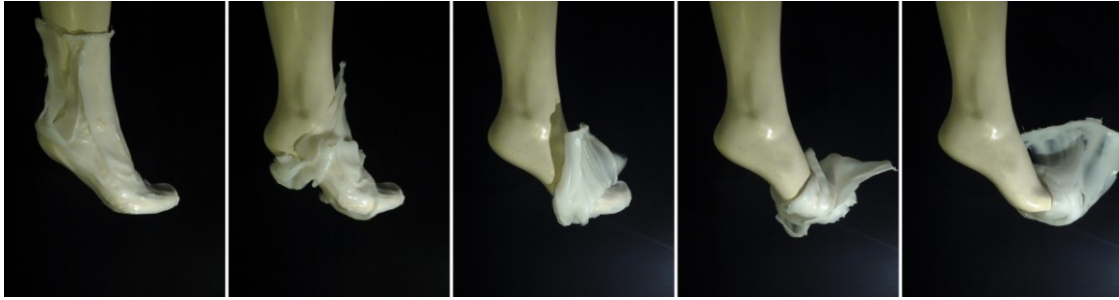


fig 7.05 Sequence of stuelpling.

A purpose made silicon sock is gradually turned inside out—or *gestuelpt*—by pulling the open end over the closed end. The inversion of the sock topology, when applied to architecture's inside/ outside duality, points to new conceptions of space that allow the creation of plural spaces through single envelopes.

The sock stuelpling experiment shows that stuelplable structures are ideally topologically open. If they are not open, such as in the case of a torus, for example, the surface needs to be opened by cutting a hole (fig 7.06). Stephen Barr explains in his Book *Experiments in Topology* (1964) that structures such a torus (doughnut) can be turned inside out [gestuelpt] by cutting a hole and 'rolling back part of the torus back on itself like the top of a stocking'.<sup>231</sup>

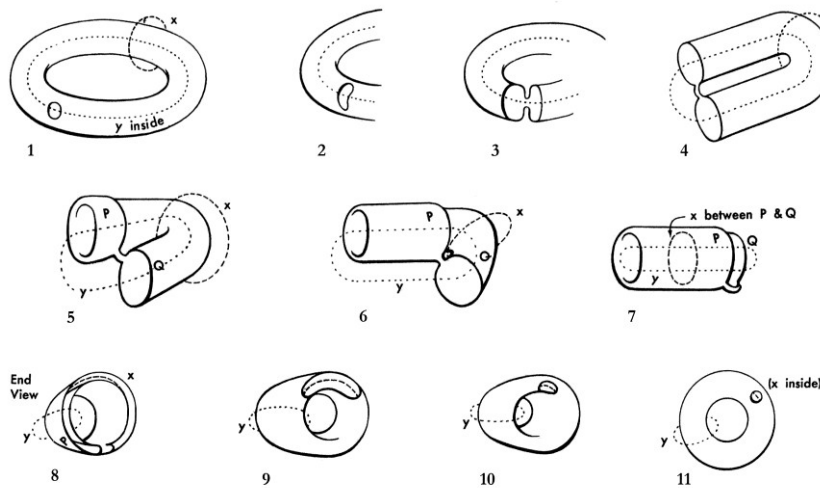


fig 7.06 The inversion of a punctured torus as shown in Barr's *Experiments in Topology* (1964).

A torus can only be turned inside out [stuelped] by cutting it. The diagrams show how a hole is created in a torus (1), widened (2-3) until only a narrow connection remains (4). In steps 5-7 the torus is rolled back on itself like the top of a sock so that the inner surface becomes the outer and vice versa. Finally, in steps 8-10 the torus opening is shrunk back and the hole reduced to its original size (11).

<sup>231</sup> Barr 1964, 138-140.

In the sock stueping experiment force is applied by manually folding the silicone sock inside out. However, when the stueping involved architectural envelopes the process would require autonomous actuation. The types of transformations involved, such as non-linear, multi-directional bending, variable stretching, and compression would be extremely difficult to achieve with mechanical means, but can be achieved with enabling technologies such as pneumorphology that take advantage of embedded motion induction and the passive dynamics and compliance of soft materials, enabling unobstructed and safe transformations.

### *Broonζ*

In order to study the requirements, conditions and potential of such space-making scenarios, I have conceived the *Broonζ* project (2013).<sup>232</sup> The project also explores methods for advancing the pneumorph technological framework through digital design. It sets out to apply the stueping morphodynamics for the creation of variable spatial conditions by transformation of its envelope. The project was started by creation of a wax model which was then sprayed with bronze coloured lacquer (hence the name) and dusted with baby powder in order to facilitate 3D digitalisation with AutoCad 123D Catch software<sup>233</sup> (fig 7.07). Following the consolidation of the geometry as mesh surface in 3D modelling software Maya<sup>234</sup> and Rhinoceros 5.0<sup>235</sup>, various transformation phases have been developed with the Maya ‘inflate’ plug-in and Z-brush<sup>236</sup> (fig 7.08), while various stueping studies have been undertaken with the Rhino ‘inverse’ plug-in (fig 7.09). Considering the project’s architectural potential, these digital studies show that stueping can provide plural spaces ranging from the secluded to the exposed.

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<sup>232</sup> This project has been undertaken in collaboration with Elias Walch.

<sup>233</sup> 3D digitalisation of objects based on photographs is very sensitive to shiny surfaces. Dusting the model with powder takes off the sheen and allows complete reproduction of geometry.

<sup>234</sup> Maya is a 3D computer graphics software by Autodesk that is used for 3D motion animation and visual effects.

<sup>235</sup> Rhinoceros (short: Rhino) is a standalone, NURBS-based 3D modelling software.

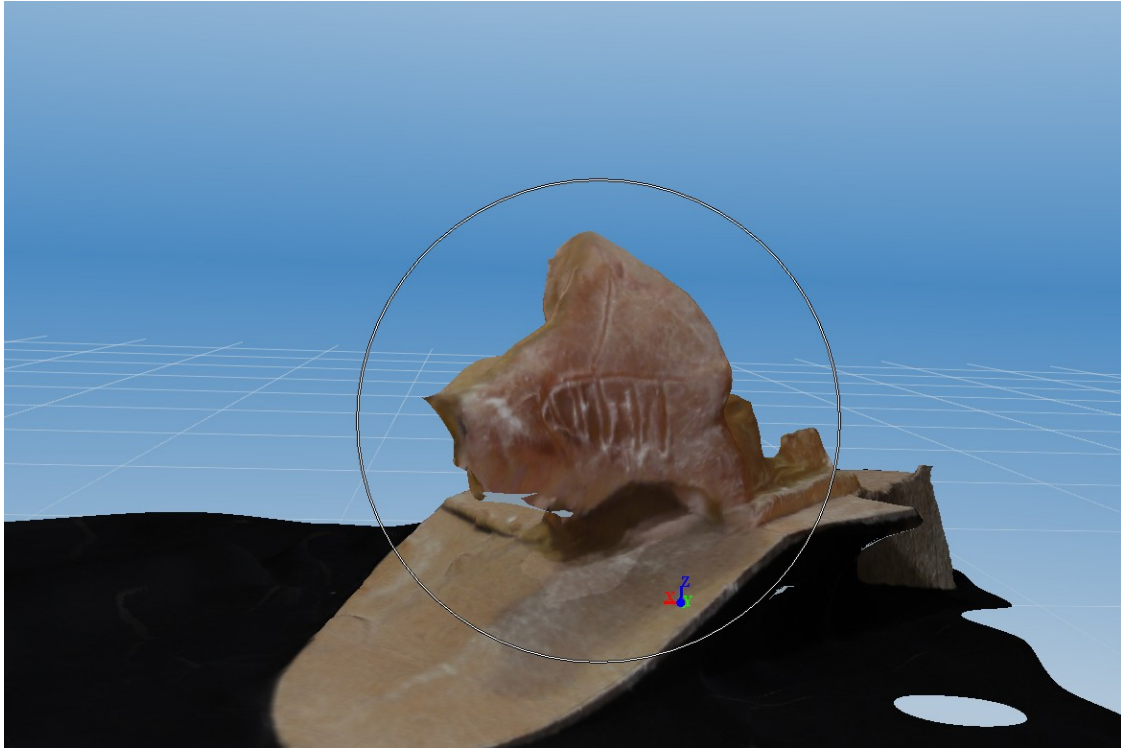


fig 7.07 Wax model for stuelping topology imported into digital space.

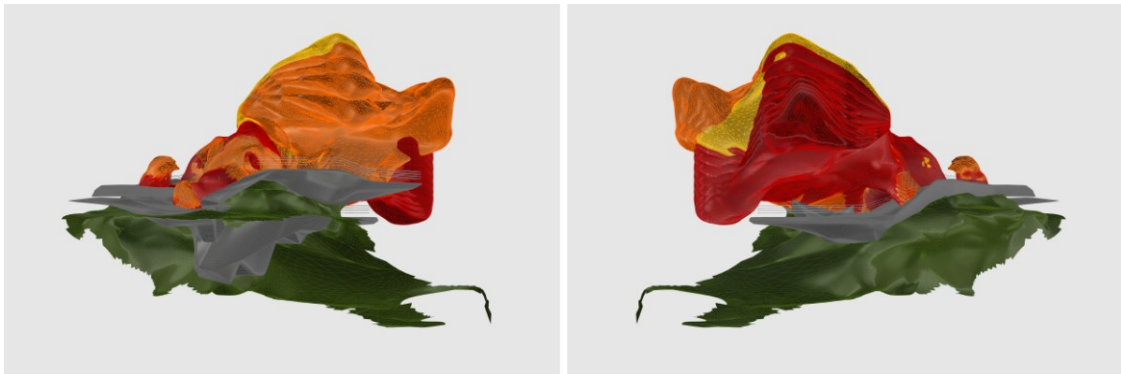


fig 7.08 Mesh geometry in various transformational phases.

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<sup>236</sup> ZBrush is a digital sculpting tool that combines 3D/2.5D modelling, texturing and painting. It was created by the company Pixologic and allows for very intuitive sculpting of the digital model with a vast range of sculpting tools and brushes.

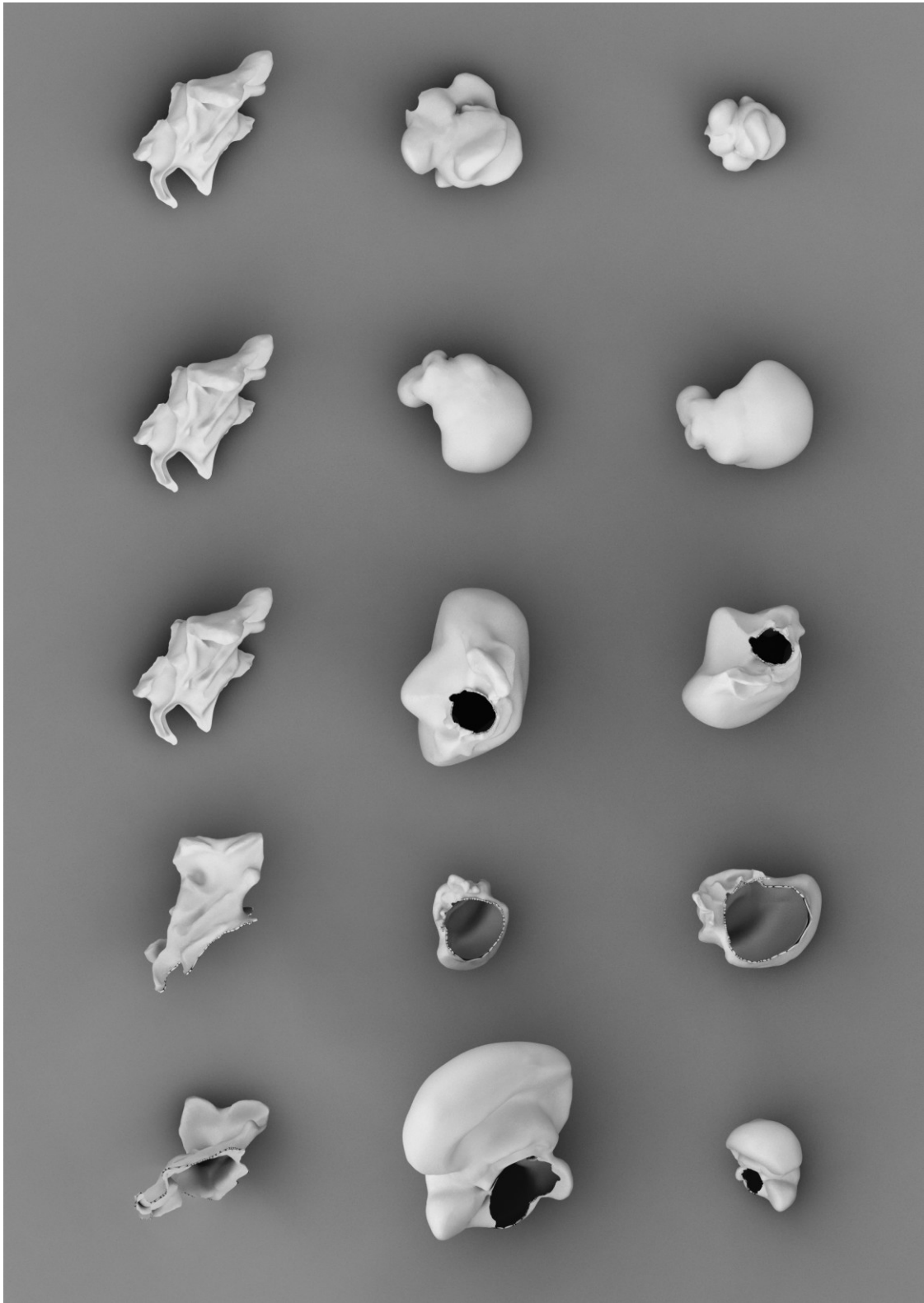


fig 7.09 Stuelping studies with Rhino 'inverse' plug in.

Through these studies I demonstrate that the topologically open structure of the *Broonx* envelope is an essential requirement for developing morphodynamic transformations that involve stueping. The digital modelling of the *Broonx* envelope revealed some insufficiencies of the digital approach when considered on purely geometrical and visual premises. Although attempts have been made to inform the digital model with knowledge gained from analogue construction and experimentation undertaken with pneumorphs [c6. s2 Pneumorphology], it proved very difficult to simulate the morphodynamic behaviour, as material properties and behaviours could not be embedded into the surface-based digital model. These observations highlight the necessity for higher integration of physical properties and behaviours into a mass-based digital model, which will be discussed further in section 3 [Morphodynamic design].

### **Edges, apertures and folds**

Depending on responses to design briefs, envelopes can morph edges, apertures or folds. *Edges* are the topological consequence of the requirement for topological openness of envelopes. In similar ways to envelopes, edges might be populated with proximity or temperature sensors and pneumorphic or hydropmorphic fields, enabling swelling and or convulsive motions. The edges could be considered by adaptation of Philip Beesley's biotechnological animism, discussed in chapter 2 [Softer architectural machines] as 'tremulous edges'.<sup>237</sup>

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<sup>237</sup> Beesley 2010 b, 24.



fig 7.10 Edges as morphodynamic structures.

In concert with edges, other primitives are envisioned to form part of envelopes. Architectural *apertures*, traditionally formed as doors or windows, would be formed by open-topological morphodynamic transformations of edges. But they can also be topologically incorporated in an envelope itself. In the first case, thermal sealing and enclosure can be achieved by synchronous morphodynamic actions such as multi-directional bending, swelling or elongation. In the latter case, openings can function like stomata, the minute pores in the epidermis of a plant leaf through which gases and water vapour pass.<sup>238</sup> They can also incorporate stuepling dynamics.

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<sup>238</sup> Kier 2012, 1255.





fig 7.11 Apertures as morphodynamic structures.

Apertures are more than mere openings. They can fulfil the functions of window opening, frame, sill and architrave by incorporating them in one morphology, while being able to adapt to changing environmental conditions as well as personal needs. The Kunsthau Graz nozzles can be considered as apertures.<sup>239</sup> While the Kunsthau nozzles are static, morphodynamic transformation would allow them to stuepl, e.g., according to ventilation patterns expressing the ventilation of the building through breath-like convulsions. This concept alludes to Aldo van Eyck's question: 'Man is still breathing in and out. When is architecture going to do the same?'<sup>240</sup>

Folds can occur as consequence of envelope bending or other compressive actions. When describing *folds* I am referring to the material dynamic consequences of material folding. I am not alluding to Derrida's fold (*pli*) concept and its appropriation by architects such as Greg Lynn in the 1990s.<sup>241</sup> Folds might physically manifest themselves as bulges or pleats in the way they may appear when fabric falls over the body, or a soft body is bent over.

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<sup>239</sup> For the nozzles see Richard, Brent. 2006. *New Glass Architecture*. London: Laurence King. pp 218-225 and Cruz 2014, 183.

<sup>240</sup> Eyck, Aldo van, 'Is Architecture Going to Reconcile Basic Values?' in *Collected Articles and Other writings*, 1947-1998. 2008. (ed.) Vincent Ligtelijn and Francis Strauven. Amsterdam: SUN. p 203.

<sup>241</sup> Lynn, Greg. 1993. *Architectural Design* [Folding in Architecture]. London: Wiley. Also see Mallgrave and Goodman 2011, 164-167.

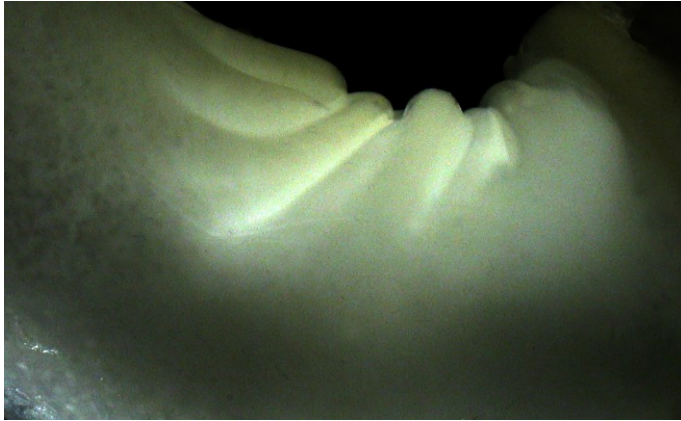


fig 7.12 Folds in *Wulster* envelope as a result of bulging, bending or compression.

### Migrating thresholds

One crucial consequence of the transformation of architectural primitives is identified in the formation of transient spatial constrictions, which I call *migrating thresholds*. In corporeal allusion to Luce Irigaray's 'lips' epigraph these thresholds can dynamically mediate different levels of involvement, closeness or openness. Thresholds in transforming spaces are not only spatial constrictions, forming 'the in-between that has taken shape,'<sup>242</sup> but can become ritual sites of passage as humans use them as 'social tools.'<sup>243</sup> In order to address such phenomena, it is worth looking at the possibility of applying the spatio-temporal theories of the French anthropologist Arnold van Gennep to discussions of morphodynamic transformations.<sup>244</sup> Although van Gennep's descriptions of the phased passage of thresholds arise from anthropological studies of rites and their social and cultural conditions, his studies also convey a sense of dynamism in the human occupation of space, as van Gennep acknowledges when stating, 'the threshold is a fundamental design element of human spatial order.'<sup>245</sup>

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<sup>242</sup> Aldo van Eyck quoted in Teyssot 2013, 156. Teyssot sets out a history of the threshold as a theme in architectural design and theory. According to Teyssot, Aldo van Eyck proposed his theory of the threshold at the end of the 1950s in order to reconcile spatial polarities such as inside-outside.

<sup>243</sup> The conception of a threshold as dynamic 'social tool' is inspired by Anthony Dunne and Fiona Raby's project 'Fields and Thresholds'. See Dunne and Raby 1995, 61.

<sup>244</sup> Gennep's theories have been applied to architecture by Walter Benjamin, but also by van Eyck and Joseph Rykwert.

<sup>245</sup> Gennep 1960. Also see Macho, Thomas. 'Schwellen in Mythen und rituellen Praktiken' in Lachmayer, Herbert/Peter Plica (ed.) 2003. *Über der Schwelle*. Wien: Böhlau. pp 23-37. p 24.

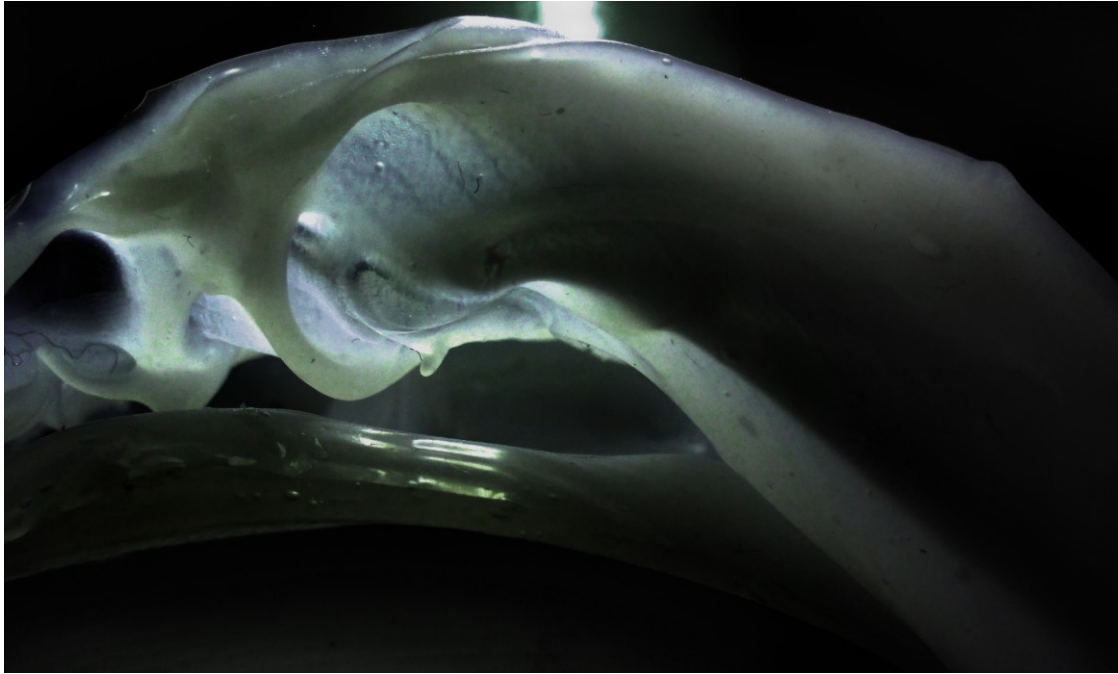


fig 7.13 Spatial proximities between epithelial envelopes.

In a morphodynamic setting, thresholds appear and disappear, infusing space with the potential of liminality. Formed between open epithelial envelopes in morphodynamic transition, thresholds migrate, as concave forms and their suggestions of seclusion and interiority morph into convex forms, suggesting exposure and exteriority. The strict duality between interior and exterior might not be overcome completely, but can lead to a discovery of liminal spaces in-between.

## s2 | The liminal space of stueiping

Projects that stueip, but don't know it yet – Topologies of in-between

Classical approaches such as in Rudolf Arnheim's *The Dynamics of Architectural Form* (1977) have built their theories on assumptions of tectonic fixity, installing dichotomies that separate a building's interior and exterior, concave and convex forms, the solid and the hollow.<sup>246</sup> Although Arnheim inscribed aesthetical and psychological dynamism to fixed architectural forms, the polar ordering of space excluded the possibility for these conditions to arise at the same time. According to George Teyssot, the problem of architecture's tendency towards separation between exteriority and interiority – one of architecture's most pervasive (and potentially restrictive) concepts – is a consequence of the conception of the body as an entity that has historically been ordered in relation to its inside and outside. Teyssot explains in his text 'A Topology of Thresholds' (2005) that architectural exteriority is reflected in similar ways to a body's relation to other bodies, while the internal organisation of organs is reflected in the internal regime of spatial order that conceives the body 'only in its *interiority*, in its regime of internal distribution, where autonomous organs (de)compose the whole into multiple parts.'<sup>247</sup> Teyssot locates the possibility to overcome the strict duality of opposites, the distinction between outside and inside, by looking at 'the space of the intermediate:' the threshold as medium that, 'by allowing entry, opens up the possibility of being in between.'<sup>248</sup> The animation of spatial primitives by stueiping establishes a completely new field for speculations about the liminal potential of architecture.

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<sup>246</sup> Arnheim 1977. Especially chapter 2 'Vertical and horizontal' and 'Solid and hollow.'

<sup>247</sup> Teyssot 2005b, 75.

<sup>248</sup> Teyssot 2013, 88 ff.

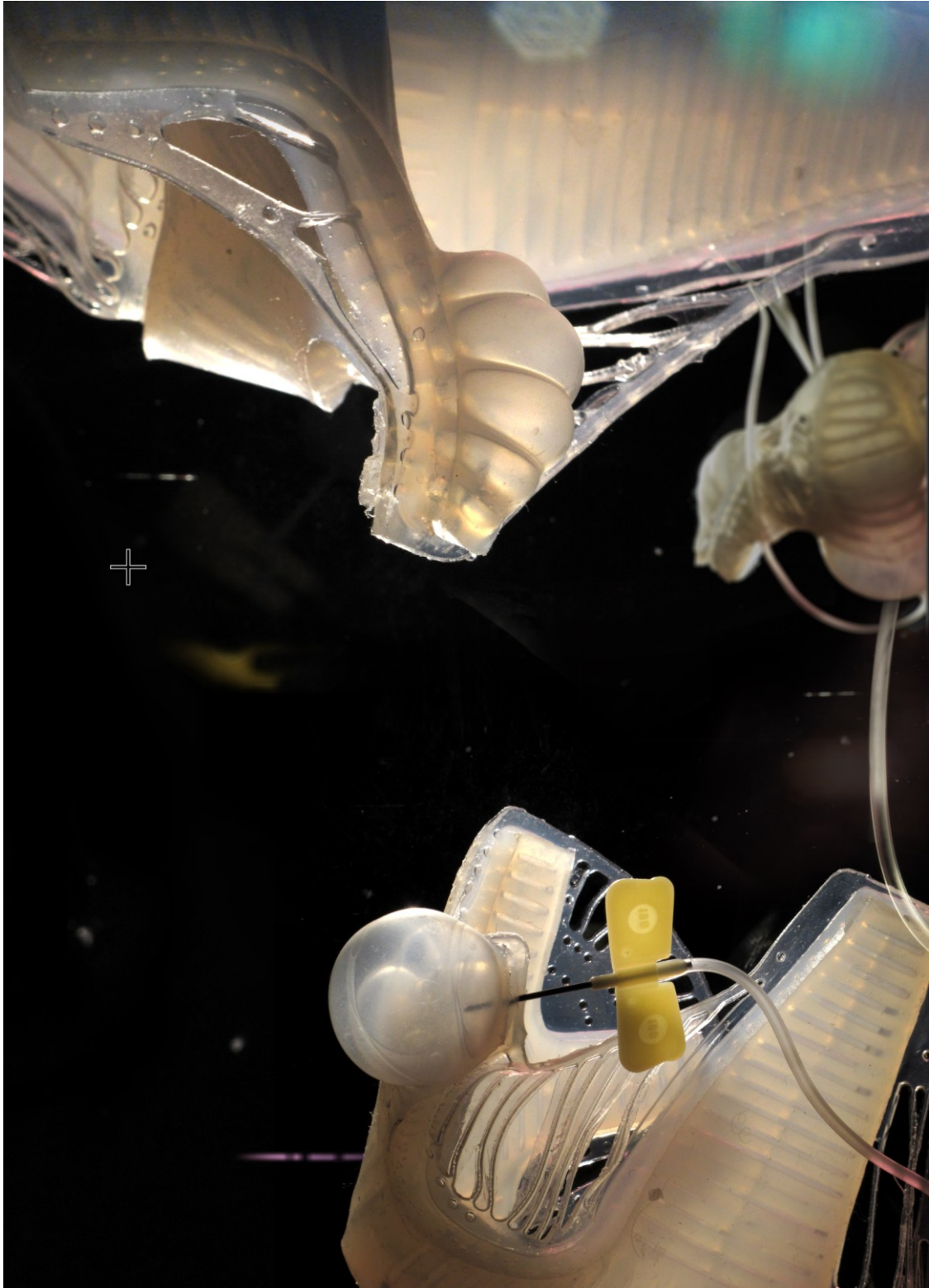


fig 7.14 Proximities between morphodynamic primitives (in this case between two *Robe* pneumorphs).



## Projects that stueelp, but don't know it yet

The following selected projects are attempts to dissolve the boundary between the exterior and interior by dynamic actuation of a building's envelope. As a consequence, the classical duality of interiority and exteriority becomes more complex, diffused and dynamically varied. Haus-Rucker-Co's *Balloon for Two* (1968), Mette Ramsgard Thomsen's *Strange Metabolism* (2007) and Omar Khan's *Open Columns* and *Gravity Screens* (2007-10) explore possibilities of dynamic space-making, processes that shall be discussed by applying stueelping as an observational filter.

### *Balloon for Two*

In Haus-Rucker-Co's project *Balloon for Two* (1967), a transparent plastic envelope is stueelped from the inside of a building to its outside. The precursor to the better known but fixed *Oasis 7* installation shown at the Documenta in Kassel in 1972, which was a fixed balloon, has been pneumatically inflated and deflated.

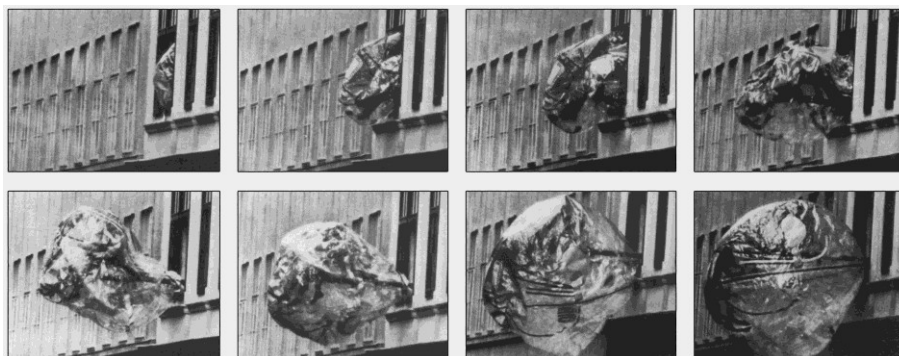


fig 7.15 Haus-Rucker-Co. *Balloon for Two*. 1967. Deployment sequence.

'Privacy was yanked from its preserve, taken out of doors, placed on view, made into a spectacle. With the projection of the inhabitants onto the exterior, the project also rejected the idea of the private subject.'<sup>249</sup>

On the 21<sup>st</sup> October 1967 at 2pm the initially unshaped envelope is pushed through the window of a first floor flat of a house at Apollogasse 3 in Vienna by pneumatic pressure – accomplished with the help of an inverted vacuum cleaner. Having passed through the window, the envelope unfolds in the public space outside becoming a spherical balloon of

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<sup>249</sup> Teyssot 2013, 238-39.

3.5m diameter.<sup>250</sup> After approximately 15 minutes, the balloon deflates and retracts into the building in order to repeat the sequence at every full hour, allowing a man and a woman to pass through the threshold upon its full expansion.<sup>251</sup> Architecturally, the stuepling of the balloon created a temporary ‘dwelling sphere’ outside the building in the public domain. The balloon can be interpreted as an inhabitable window, where a part of the building envelope has been stuepled, allowing inhabitants the physical passage of a threshold and inhabitation of a zone outside that would otherwise not be inhabitable.

### *Open Columns and Gravity Screens*

With *Open Columns* (2007) and the *Gravity Screens* (2009-10) Omar Khan has demonstrated on larger-than-human scales that architectural machines can be constructed around the idea of flexibility and distributed motion induction. Khan explains that the projects explore ‘the elastic potential of synthetic rubbers for architectural surfaces.’<sup>252</sup> The morphodynamic transformation of the screen consolidates their geometry with the passive dynamics and compliance of the elastomer materials.



fig 7.16 Omar Khan, *Open Columns*, 2007

Flexible multi-grade material deployable columns suspended in exhibition space. Application of vertical down-force causes the screens to stretch and the apertures open up, while application of vertical up-force causes the screen apertures to close.

<sup>250</sup> Haus-Rucker-Co, 1984, p.72, original German, transl. by author.

<sup>251</sup> Haus-Rucker-Co 1984, 72.

<sup>252</sup> Khan 2011, 59.

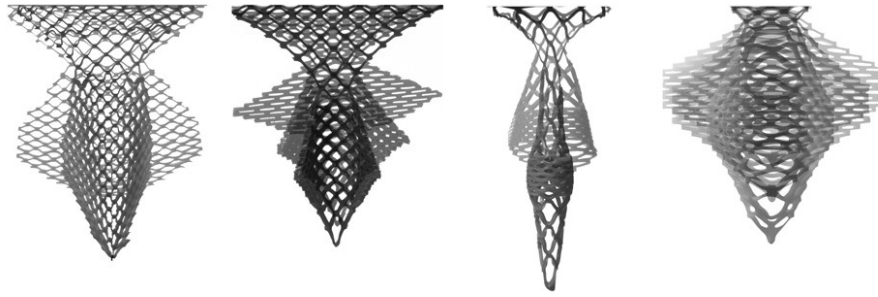


fig 7.17 Omar Khan, *Gravity Screens*, 2009-10

Elasticity studies of different types that explore their formal transformation from flat to volumetric as a result of gravitational pull.

The elastomer grids of the projects can be adjusted through transformation. Khan explains that the ‘manipulation of the screens “softens” the architectural boundary.’<sup>253</sup> In the case of *Open Columns*, the shape of the screens, with a smaller diameter at the bottom end and a wider diameter at the top end, support the stuepling process when the bottom end is stuepled into the inside of the top. The space can be adjusted and configured. Through the stuepling of the columns the space in which the columns are suspended, as well as the space of the columns, becomes a plural space, capable of being adjusted and reconfigured according to human needs.

### *Strange Metabolism*

Topologically more intense transformations of architectural envelopes are proposed in Mette Ramsgard Thomsen’s and Toni Hick’s collaborative project *Strange Metabolism* (2007).<sup>254</sup> The project ‘investigates the idea of an architecture moving not merely to reflect user optimization, but rather according to its own rhythms of folding and unfolding, closing and opening to inhabitation.’<sup>255</sup> Alluding to its urban siting, Ramsgard Thomsen invites us to ‘imagine if a city could become a place where its fabric – walls, floors, and facades – became dynamic, where life would be reflected into the built world, and spaces

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<sup>253</sup> Khan 2011, 57.

<sup>254</sup> See project description and video at [http://cita.karch.dk/Menu/Projects/Behaving+Architectures/Strange+Metabolisms+\(2007\)](http://cita.karch.dk/Menu/Projects/Behaving+Architectures/Strange+Metabolisms+(2007)), accessed 2013/03/28. The project was undertaken in the course of a research collaboration between Mette Ramsgard Thomsen, CITA and Toni Hicks, Constructed Textiles, University of Brighton.

<sup>255</sup> Ramsgard Thomsen 2007, 37.



could shift and change...'<sup>256</sup> An urban utopia that 'imagines the making of a textile architecture, a knitted skin – wrapping, folding and pleating as it links the inside to the outside, the intimate to the public,' the project proposes a dynamic conception of architecture.<sup>257</sup> Interior spaces are stuelpt into exterior spaces as its 'skins posit shifts between interiors and exteriors through their folds, protrusions, slits and layerings.'<sup>258</sup>



fig 7.18 Mette Ramsgard Thomsen and Toni Hicks. *Strange Metabolism*. 2007.

The project is an utopian scale model of a city, made from machine-knit structures that come to life through simple stop-frame animation. 'The models are animated through dynamic armatures allowing the membranes to collapse and expand the spaces they suggest.'<sup>259</sup>

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<sup>256</sup> Ramsgard Thomsen 2007, 37.

<sup>257</sup> Ramsgard Thomsen 2007, 39.

<sup>258</sup> Ramsgard Thomsen 2007, 39.

<sup>259</sup> Ramsgard Thomsen 'Robotic Membranes' in Sheil 2008, 96.

These projects have articulated strategies for the creation of plural spaces through stuepling. By taking advantage of the soft and pliable characteristics of materials used, their envelopes could be turned inside out or given another direction through the bending and flexing of their surfaces, thus dynamically re-articulating the relations between their interior and exterior spaces. Only by liberating their constructions from mechanically intrusive transformation mechanism or discrete and fixed conceptualisation of openings, were these projects able to approach the spatial problem of interior-exterior division by offering solutions that involved the stuepling of their envelopes.

### **Topologies of in-between**

From modernist orthodoxy to digital design, traditional conceptions tend to formulate the relations of a building's interior and exterior with static enclosures. Penetration of this enclosure is the necessary consequence in order to permit access, exchange and interface. Sigfried Giedion noted in *Architecture and the Phenomena of Transition* (1971) that 'a completely new chapter in the history of architecture was started with the opening up of the solid surface of the wall, and the resultant interpretation of interior and exterior space.'<sup>260</sup> The strategy for Giedion's retrospective transformation of enclosures was penetration and cutting of discrete openings.

By conceiving of openings and passages as non-discrete but morphodynamically formed (and un-formed) openings, the mediation of the interior-exterior duality – the topology of the in-between – can be played out by less restrictive conditions. In *A Topology of Everyday Constellations* (2013), Teyssot proposes a new reading of discrete elements such as the door and the window, but also their cognates the mirror and the screen, as thresholds or interstitial spaces. Following on from his earlier ideas of a hybrid architecture as prosthetic of the technologized human body [c3.s3], Teyssot argues that the division of interior and exterior installed by traditional readings can be overcome when they are seen as a middle space, an in-between that holds the possibility of technologically mediated exchanges and encounters. Morphodynamic transformations of envelopes and stuepls can create non-discrete liminal spaces that no longer separate the exposed (public, external) from the secluded (private, internal).

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<sup>260</sup> Giedion 1971, 159.

### *Oasis 8 – Compliance House I*

With this study I explored the possibility of creating poly-descript space through polymorphism.<sup>261</sup> *Oasis 8 – Compliance House I* (2013 – ongoing) not only alludes to Haus-Rucker-Co's *Oasis 7* installation at the documenta 5 but also uses the infinite topology of the figure 8 as point of departure to reflect about the possibility to create by means of transformation many spaces with one morphology, while at the same time entangling the secluded (internal) with the exposed (external).<sup>262</sup> In *Oasis 8* the fluctuation of privacy is expressed emphatically through the morphodynamic convulsions of the architectural surrounding. As a spatial switch the stuelpable topology of *Oasis 8* assumes the shape of a topologically open sphere when closed. Its topological description becomes more complex during the stuelping phases.

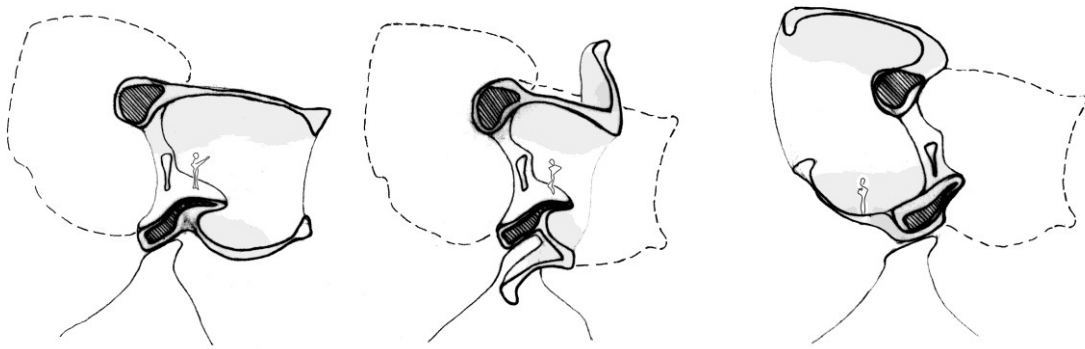


fig 7.19 *Oasis 8*. 2013.

Sequence sketch of stuelping phase. The spherical, but topologically open, envelope is fixed to a support structure in such a way that a full stuelping of the envelope can be facilitated.

One crucial aspect of the stuelping transformation of the *Oasis 8* envelope is the ascription of internality to surfaces that have previously been external. As the envelope opens up, the internal surface that has previously been internal becomes an external surface. Considering the project as a facade study it becomes clear that embedded functions such as fluidic networks can have multiple functions depending on the stuelping phasing. It is conceivable that fluidic networks are used as a solar collectors when the

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<sup>261</sup> This study is in its conceptual phase. I intend to develop this project further and I include some conceptual ideas here as they signify the developments envisioned for further research into areas sygc as stuelping – polymorphism and morphodynamic aspects of embodied architecture.

<sup>262</sup> The obvious references are Kiesler's Endless House and Ben van Berkel's obsession with the infinite diagram as building (Moebius House, Mercedes-Benz Museum).

envelope exposes the network to the exterior. If it stuelps the network to the interior the same network might be used for temperature conditioning of internal space.

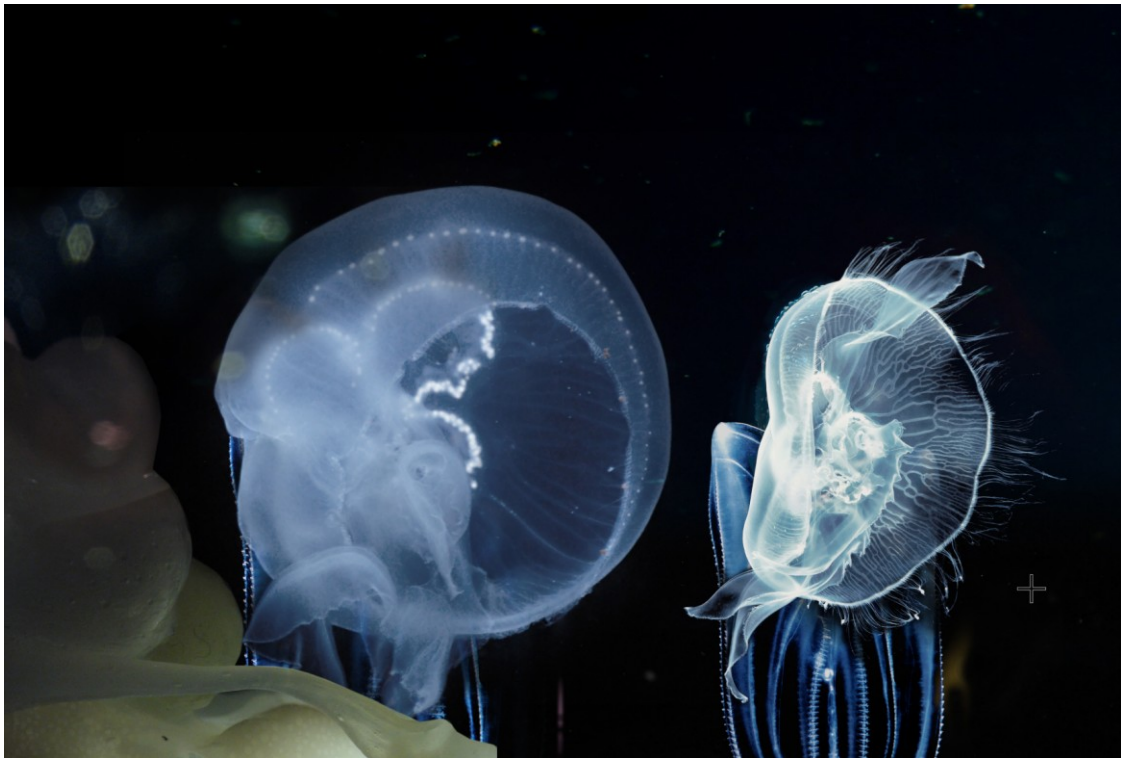


fig 7.20 *Oasis* 8. 2013.

Illustration showing possible scenario with soft machines for experimentation with notions of embodied architecture.<sup>263</sup> The stuelpable façade of the house is composed of epithelial envelopes with embedded fluidic and lighting systems, tactile edge sensors and pneumorphic fields.

### *Corporeal metaphors of stuelping*

For art historian James Elkins the body itself is a model for overcoming the inside-outside polarity, as its the infoldings and outfoldings of its various orifices – some are permanently open, like the nose; some are stoppered, as the ear is – are too various to sustain the polarity.<sup>264</sup> For Elkins the body is ‘a collection of pockets’ that are folded in or out of the body, allowing the outside to infiltrate the inside and the inside to exchange

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<sup>263</sup> Image material from Guido Mocafico. 2006. *Medusa*. Göttingen: Steidl.

<sup>264</sup> Elkins 1999, 42. Elkins further points out that ‘infoldings’ are described in medical terms as ‘invaginations’ and complimentary ‘outfoldings’ are primarily sexual: the labia, clitoris, penis, prepuce and the scrotum.

with the outside.<sup>265</sup> Corporeal openings and orifices as sensitive sites, according to Elkins, have developed from the skin's constituent properties by 'infolding' and 'outfolding',<sup>266</sup> for which he employs the topological metaphor of turning a sock inside out:

If I turn a sock inside out, then the area that once enclosed my foot now "encloses" the world, and I have trapped the outside in the inside. For that reason, the world on the other side of the skin can be reimagined as an inverted pocket, analogous to the smaller pockets within the body.<sup>267</sup>

According to Elkins, 'infolding' is a common occurrence in biological membranes and the resultant liminal passages where familiar skin turns inward to the body are mostly transitions from epidermis to mucous membrane,<sup>268</sup> a relation that when projected into architectural envelopes can be instructional for their sensitisation and capacitation. In *A Thousand Plateaus* (1980) Deleuze and Guattari evoke a newly capacitated topology arising from the conditions created by the body as 'multifaceted surface':<sup>269</sup>

It is also the skin as envelope or ring, and the sock as reversible surface. It can be a house or part of a house, any number of things, anything [...] A body without organs is not an empty body stripped of organs, but a body upon that which serves as organs [...] is distributed according to crowd phenomena, in Brownian motion, in the form of molecular multiplicities. [...] The body without organs is not a dead body but a living body all the more alive and teeming once it has blown apart the organism and its organisation [...] The full body without organs is a body populated by multiplicities.<sup>270</sup>

As Teyssot points out, '[w]ithin this topology, dwellings come across as something reversible, like the skin of a dead animal, or the form of a sock. Forging a new kind of

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<sup>265</sup> Elkins 1999, 42.

<sup>266</sup> See 'The Concept of Membranes' and 'Inside and Outside' in Elkins 1999.

<sup>267</sup> Elkins 1999, 44.

<sup>268</sup> Elkins 1999, 37.

<sup>269</sup> Teyssot 2013, 221.

<sup>270</sup> Deleuze and Guattari in Teyssot 2005a, xx; Original quote in Deleuze and Guattari 1980.

organicism, the interior becomes exterior, while vice versa the exterior folds itself into surfaces that may be folded and unfolding, invaginated or extragastrular.<sup>271</sup>

### *Laryngeal Mesomachine*

Epithelial envelopes and stuepls can be envisioned to embody capacitated topologies in a similar sense as natural bodies connect, absorb and dissipate by unfolding and infolding their skin, flesh and organs. But how can architecture be designed around a human being that seems to disappear into technology? Can morphodynamic transformations of primitives around, above, and underneath human beings lead to new spatial protocols of in- and cohabitation with an architecture that is as embodied as we are, allowing more seamless and symbiotic relations? These questions have led to my project *Laryngeal Mesomachine* (2011- ongoing). The project envisions an organ recital space and takes its intellectual departure from a Raymond Rousellian double-reading<sup>272</sup> of the word ‘organ’ that inspires the musical organ with the organicism of its biological equivalent, the larynx, while the scale of the musical church organ inspires the organic larynx to become architectural [c2.s3. Organon-machinae synthesis].<sup>273</sup> In short, the project speculates about an architectural environment that is generated by inversion of the human larynx into space.

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<sup>271</sup> Teyssot 2013, 222. Gastrulation occurs in the very early embryonic development of most animals, involving the change of the topological structure from a sphere (blastula) to the torus (gastrula). Teyssot’s term ‘extragastrulation’ is not a common English term but is likely to allude to the four extra-embryonic tissues in vertebrate embryos evolving from the blastula: amnion, chorion, yolk sac and the allantois. In placental animals these tissues form the placenta.

<sup>272</sup> Raymond Roussel, the French writer, novelist and poet, described his literary technique of using a word or phrase that can potentially contain multiple meanings in order to construct a narrative between them. See Roussel, Raymond. 1995 [1935] *How I Wrote Certain of my Books* [*Comment j’ai écrit certains de mes livres*]. transl. Trevor Winkfield. Cambridge, Mass.: Exact Change.

<sup>273</sup> Also see Joseph Rykwert’s notes on the musical organ. See Rykwert 1992, 340-41 in Braham and Hale 2007.



fig 7.21 *Laryngeal mesomachine*. 2011 – ongoing.  
General views.

The *Laryngeal Mesomachine* is conceived as an embodied model for a space in which organists can recite their music by playing an organ that is integrated on a system-level-symbiosis with the building, while the audience and organists are symbiotically connected with one another through the organ.

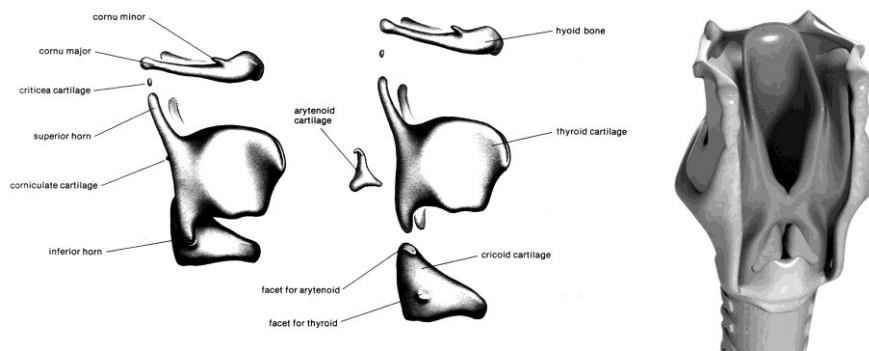


fig 7.22 Human larynx with cartilage.

For sound generation and manipulation of pitch, frequency and volume the larynx works together with the vocal tract, the pharynx, the mouth the lips and the muscular hydrostat sitting directly above it, the tongue.

The term ‘laryngeal’ alludes to the human larynx and its multi-functional capacities, described in Fink and Dermarest’s *Laryngeal Biomechanics* (1975), while ‘mesomachinery’



locates entities of the size of animals and organs between macromachines (galaxies, planets, cities) and micromachines (cells, molecules).<sup>274</sup> Fink and Dermarest count the larynx amongst nature's most lavish mechanical inventions. They note that for its size 'the human larynx is a remarkably versatile instrument – a cavernous duct for ventilation, a vibratile slit for varied sound generation, an exit plug for gas-tight postural effort, and an entrance barrier and deflector of potential invaders.'<sup>275</sup> The physiology of the larynx and its integral function in the human body inspires the design of the organ recital space that is composed of morphodynamic primitives.



fig 7.23 *Laryngeal Mesomachine*. 2011 – ongoing.

Structural cartilage for harnessing soft morphodynamic (partial) bodies and internal view.

For an attempt to approach possible relations arising between organist, audience and the organ building, Peter Sloterdijk's first book of his *Sphere* trilogy, *Spheres. Vol 1. Bubbles*

<sup>274</sup> The prefix *meso-* denotes the middle or in-between. For the term 'mesomachine' see Hall 1975 vol 2, 52. According to Hall Julien Offray de La Mettrie described the human body being composed of mesomachines, also alluding to the notion that a mesomachine such as a muscle depends partly on the workings of its micromachinic components, fibres and blood vessels.

<sup>275</sup> Fink and Dermarest 1975, v.



(2011 [1998]) becomes significant. A self-described ‘student of air,’ Sloterdijk promotes an ‘atmospheric’ thinking about processes and practices that bind human and non-human elements together. Sloterdijk’s approach allows projecting the inherently pneumatic condition of human being into the architectural realm, thus capacitating architecture itself as co-constituting and co-constituted through shared origins and developments.

Every subject in the real consubjective space is containing, in so far as it absorbs and grasps other subjective elements, and contained, in so far as it is encompassed and devoured by the circumspections and arrangements of others. The real human proximity field is thus more than a simple system of communicating vessels; if your fluid rises in my tubes and vice versa, this is only the first indication of what allows humans to affect one another at close range through their joints and overflows.<sup>276</sup>

Accordingly, and paraphrasing Sloterdijk, the relation between human beings and embodied architecture can be described as ‘a relation of open containers in unrest, containing and excluding each other at the same time.’<sup>277</sup> An architecture composed of morphodynamic morphologies and their cognates, could become an active participant in the social and cultural interactions related to the recital of organ music, asking its audience to begin, develop, learn and unlearn the mutual conditioning of embodied experiences between them and their surroundings.

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<sup>276</sup> Sloterdijk 2011, 88.

<sup>277</sup> Sloterdijk 1998, 84; transl. by author.

## s3 | Designing the embodied

Self-model – Embodiment – Morphodynamic design – Prototyping and Construction

This section is about inspiring the morphodynamic design space of architecture with ideas and methods developed in soft robotics. When architecture is conceived as an environment that seeks to offer a more seamless exchange with humans, insights gained from research on embodiment in soft robotics can provide a better understanding of the narrowing gap between us and our designs. Design spaces of many soft robots and those of architecture share their anthropologic outlook, and progressively intensifying reciprocities between human beings and machines are stimulating speculations within these spaces to conceive of architecture in active rather than passive terms. In the year 2000 Roy Ascot made a bold prediction about the future of architecture:

‘As the century advances, the paradigmatic change in architecture will be registered at the level of behaviour rather than form. [...] the 20th century’s exaggerated interest in what a building looks like, its mere appearance, will give way to a concern with the quality of its gaze, how it sees us, how it perceives our needs. Questions of the physical structure of buildings will be overshadowed by ambitions for their dynamism and intelligence, their ability to interact with each other and with us, to communicate, learn and evolve within the larger ecology. [...] The goal will be the building of sentience, a moist architecture that has a life of its own, that thinks for itself, feeds itself, takes care of itself, repairs itself, plans its future, copes with adversity. It will be a technoetic architecture that is as much emotional as instrumental, as intuitive as ordered.’<sup>278</sup>

Irrespective of visionary speculations about possible futures, Ascot’s prediction also provokes the question in how far these capacities are already available. Instead of writing about a building Ascott could have written about a robot and the prediction would read

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<sup>278</sup> Ascott 2000, 6.

less provocative, given that now, over a decade later, we are able to take into account contemporary developments in AI and soft robotics research. In these fields, behavioural and dynamic characterisation is often discussed on the basis of the concept of embodiment, which has been adapted by robotics during a major paradigm shift in the 1980s.<sup>279</sup> As soft robotics deals with the physical embodiment in artificial bodies, its approach to embodiment provides a more suitable point of conceptual departure for discussion of embodiment in architecture. However, it is critical to distinguish embodied approaches in robotics (that tend to develop autonomous moving entities) with an embodiment concept that is applied to a sited, tethered body of architecture.<sup>280</sup> Consequently, the embodiment of an architectural project should be carefully considered as embodiment also implies that constituent parts of a body exert influence on how it perceives itself and its surroundings. For example, the movement capabilities must match those of the visual system: a snail with visual organs as good as those of humans could not process the neural information as it lacks the corresponding brain, not to speak of converting the input into physical action.<sup>281</sup> Beyond its trivial meaning, i.e. ‘intelligence requires a body,’ the concept has deeper implications concerned with how a corporeal structure and its control are related to one another, while also in constant exchange with the environment.

## Self-model

In Negroponte’s vision of ‘viable responsiveness’ ‘[m]y house needs a model of me, a model of my model of it, and a model of my model of its model of me.’<sup>282</sup> But most importantly, the house needs a model of itself. Such *self-models* are the basis of soft robotic designs that employ self-learning algorithms based on kinetic feedback and morphological

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<sup>279</sup> Pfeifer and Fumiya 2004.

<sup>280</sup> This is the issue with which all adaptive/ responsive/ interactive architectural installation/ machines/ devices are grappling; taken that they aspire autonomous behaviour.

<sup>281</sup> For example see Pfeifer 2004, 81. For deeper neuro-scientific and neuro-philosophical implications, see Thomas Nagel’s influential paper ‘What Is It Like to Be a Bat?’ in which he argues that an organism has conscious mental states only if it feels like being that organism and that its body influences the attainment of the conscious state. Nagel, Thomas. ‘What Is It Like to Be a Bat?’ in *The Philosophical Review*. vol 83. no 4. October 1974. pp 435-450.

<sup>282</sup> Negroponte 1975, 151.

computation.<sup>283</sup> For self-models of embodied architecture they can be created by correlation of their structural morphology and morphodynamic capacities, including but not limited to cavity layout and structure, pneumatic pressure and velocity, elasticity, Shore hardness with feedback from sensory input, elongation and others. The self-model would then be able to negotiate movement pathways of its body with information registered from embedded sensors, such as proprioceptors (position of components) and mechanoreceptors (mechanical impression, strain and movement), temperature or proximity sensors and visual and sonic recognition devices.

### *Redundancy*

Design exhibiting multiple direction bending and high degrees of freedom (DOFs), facilitated by soft and elastic components such as morphodynamic primitives, have very high redundancy. For instance, because we can grasp and manipulate an object in various ways with our hand – due to its many joints and high degrees of freedom (DOFs) – the human hand is kinetically redundant. Our hand is attached to a multi-axial body. But if the body is soft without skeleton and joints, such as in an octopus, the system is ‘hyper-redundant’ and becomes complicated because of the high DOFs.<sup>284</sup> But higher levels of kinetic redundancy in robots allow it to achieve tasks in different ways. Rather than being a problem, redundancy is a fundamental strategy for flexible adaption, learning and subsequent liaison with the environment. In architectural terms, the redundancy of soft and elastic, pliable and transformable components needs to be considered – not only as part of the kinetic design but also as part of a system’s capability to learn, sense and intervene.

### **Embodiment**

As the self-model of soft robots is informed by its ‘corporeal’ basis and redundancy, the robot needs to understand the mechanical behaviour of its soft materials. ‘This is where

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<sup>283</sup> Pfeifer et al 2012b, 85.

<sup>284</sup> Sumbre et al 2001, 1845-1848.

learning becomes critical. The robot needs to figure out things by itself.<sup>285</sup> In order to achieve this, designers need to understand and exploit the notion of embodiment. Pfeifer et al point out that, in the context of learning by imitation the embodiment has to be carefully considered; such learning will be different to human learning because the mechanical properties of robot bodies are completely different from those of the human teacher.<sup>286</sup> In architectural terms, embodiment enables designers to conceive of architecture as an environment that can learn, unlearn and accommodate human behaviour and environmental changes based on its own corporeal reality. While providing an environment for human inhabitation the architecture itself is sited in an environment, adapting to seasonal and more immediate changes.

### *Learning and control*

Part of the challenge of conceiving of embodied structures is the question of how an embodied architecture can learn about itself and react with appropriate behaviours. Researchers in soft robotics are trying to figure out how a robot's anatomical characteristics, material properties, and location of sensors and actuators - amongst other things - can be incorporated with the information processing performed by the controller.<sup>287</sup> The challenging aspect of the embodied approach is that certain decisions and controls have to be given to the machine, and consequently the separation between control and the controlled is no longer clear.<sup>288</sup> Some of the strategies currently explored in soft robotics involve letting robots explore and learn on their own. Soft robotics and AI researcher Pfeifer explains that this behaviour would be similar to observations made in learning humans. 'It's related to motor babbling, a term used in developmental science. It will have a certain degree of randomness. However, even if the motor signals are random, the robot's movements will be constrained by the morphological and material characteristics of the system.'<sup>289</sup> By adapting these strategies, embodied architecture can be

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<sup>285</sup> Pfeifer 2012a, 123.

<sup>286</sup> Pfeifer et al 2012b, 80.

<sup>287</sup> Pfeifer 2012a, 123; Pfeifer 2012b.

<sup>288</sup> Pfeifer 2012a, 124.

<sup>289</sup> Pfeifer 2012a, 124.

enabled to exploit its morphodynamic constraints and through this feedback figure out its own dynamics and space-making potential.

### *Sensing*

Sensors are not excluded from the softening disruption undergone by machines and robots, and as part of a broader research effort into ‘soft matter’ electronics ‘stretchable sensors’ are being developed ‘that register deformation and surface pressure.’<sup>290</sup> Carmel Majidi, principal researcher at Carnegie Mellon University’s Soft Machine Lab states that these kinds of sensors represent just one aspect of the much broader and potentially revolutionary fields of elastically stretchable electronics and computing.<sup>291</sup> For example, CB<sup>2</sup>, a child humanoid robot designed for studies on robot learning and human-robot interaction, is covered with a fully sensorized skin and flexible joints.<sup>292</sup> Integrated with soft, pliable and transformable components, such as actuators or enveloping skin or other structures undergoing deformation, these sensors can inform the self-model with data including component positioning (proprioceptors) and mechanical impression, strain and movement (mechanoreceptors).

### *Tuneable materials*

Iida et al. expect that the investigations of soft and smart materials will bring robotics research beyond its current capacities.<sup>293</sup> Soft robots fitted with components that are electrically conductive, optically transparent, independently functional (e.g. as sensors, fluidic devices, transducers or analogue computers) or biocompatible could open entirely new types of applications, but would require materials with appropriate properties.<sup>294</sup>

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<sup>290</sup> Majidi et al 2010, 1.

<sup>291</sup> Majidi et al 2010, 1.

<sup>292</sup> Minato, T., Yoshikawa, Y., Noda, T., Ikemoto, S., Ishiguro, H., and Asada, M. ‘CB2: A child robot with biomimetic body for cognitive developmental robotics’ in *Humanoid Robots: 7th IEEE-RAS International Conference*. 2007, pp. 557-562.

<sup>293</sup> Iida et al 2012, i.

<sup>294</sup> Such materials could be created through reassembly and manipulation of matter on the nanoscale by taking advantage of physical phenomena such as Brownian motion, van-der-Waals-forces and viscosity, as suggested in Jones 2004.

Materials with anisotropic mechanical properties along different directions or with different mechanical behaviour at different pressure ranges would provide the basis for a wide range of non-linear motions.<sup>295</sup> For instance, materials with actively tuneable compliance could be useful for agile machines that could locally change the properties of the material and enable fundamentally new strategies for manipulation.<sup>296</sup>

## Morphodynamic design

In considering form-finding as part of the concept of embodiment the question emerges which body design can incorporate the mutual conditioning of its co-constituting components. The dynamic and soft system approach inspires a reconsideration of the architectural approach to form-finding, which tends to employ form as a container of material (*morphodectic*). One consequence of the embodied approach is to fundamentally rethink architecture's relation to form on the basis of generation of form on the basis of material properties (*morphogenetic*).<sup>297</sup> Rejecting the idea of matter as receptacle of form in favour of a co-constituting approach that can incorporate material properties in a kind of self-model are currently explored with morphogenetic design strategies.<sup>298</sup> These developments give rise to speculations about architectural designs that can find their own corporeal basis, and communicate them to their designers.<sup>299</sup> Echoing developments in soft robotics, these developments will significantly advance the digital understanding of

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<sup>295</sup> Ilievski et al. 2011, 1894.

<sup>296</sup> Current technologies with shape-changing properties such as shape memory alloys (SMAs) and electroactive polymers (EAPs) have restricted usage. EAPs tend to have two deformation shapes that can be controlled to transform from one to the other, while SMAs only have a single usable shape memory and require an external actuator to return it to its original shape. See Coelho and Zigelbaum 2009, 163.

<sup>297</sup> DeLanda, Manuel. 'Deleuze, Diagrams and the Genesis of Form' in *ANY* [Diagram Work: Data Mechanics for a Topological Age]. no 23. June 1998. pp 30-34.

<sup>298</sup> Menges 2012.

<sup>299</sup> Coelho and Zigelbaum point out that the need to simulate the transformational properties of shape-changing materials can be met with parametric design tools. These allow for the creation of complex three-dimensional forms, which can 'adapt in response to changing conditions and parameters' and 'support the design of physically transformable forms' (2011, 172). Cristiano Ceccato explains that currently 'constructive solid geometry (CSG) modeller software tools' enable designers to embed material properties directly into the (parametric) design model. (Ceccato in Menges 2012, 100).

architectural construction through embodied design strategies.<sup>300</sup> In order to bring these strategies to fruition, it is critical to acknowledge that a higher integration of morpho/genetic/dynamic/logic design knowledge can only build on a profound understanding of material properties and how these can be employed on a system-level symbiosis.

### *Morphological computation*

One method for higher integration in morphodynamic design strategies is morphological computation. Knowledge gained from research into biological concepts of morphology and the corporeal basis of intelligence – or Embodied Intelligence (EI) – are bringing to the discussion that ‘certain aspects of the computation can be off-loaded to morphological and material components.’<sup>301</sup> Pfeifer points out that ‘[b]iological systems which are – with the exception of the skeleton providing structural support – largely soft and elastic (to varying degrees), capitalize on “morphological computation” by exploiting their morphological and material characteristics as well as processes of self-organization.’<sup>302</sup> Movement of the human body – for instance in walking or gymnastics – relies intrinsically on the elasticity of the muscle-tendon complex while on the sensory side the body provides feedback about posture and stimulus. This is the venue where the non-trivial meaning of embodiment – beyond the corporeal basis of intelligence relation – becomes relevant.<sup>303</sup> Whenever a body behaves, or moves in an environment, it affects that environment, and in turn is affected by it. Assuming that architecture, when conceived as embodied, can sense and integrate its actions and compliance into its self-

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<sup>300</sup> Software programs such as Soft Image XSI, Maya, Rhino have physical engines that allow simulation of kinetics, adjustment of physical parameters such as gravity, friction, inertness or fluidity instead of abstracted and reductionist simulation of visual qualities. These are not FEM analytical tools such as in Abacus but these strategies enable designers to situate the model in a virtual physical environment and assign physical attributes to the model itself.

<sup>301</sup> Pfeifer et al. 2012, pp.

<sup>302</sup> Quote from keynote lecture ‘Morphological Computation - Self-organization, Embodiment, and Biological Inspiration’ of Rolf Pfeifer at International Joint Conference on Computational Intelligence, Barcelona, Spain, 5-7 October, 2012. Available at <http://vimeo.com/52143418>; accessed 2013/09/13.

<sup>303</sup> Pfeifer and Iida 2005, 48.



model, then it could benefit from ‘off-loading’ computational efforts into its morphological design and material dynamics.

### *Non-linear models*

Soft machine researchers, such as Robert F. Shepherd et al have pointed out that the response to actuation of machines with elastomeric structures is ‘highly nonlinear and thus predictive modelling of their actuation is currently empirical.’<sup>304</sup> In order to improve understanding of the non-linear behaviour of soft and composite structures, physical computer models and multi-physics approaches are needed for the modelling of soft morphologies and their transformational potential, involving ‘simultaneous analysis of solid and fluid mechanics, kinematics, electro-mechanics, thermodynamics and chemical kinetics of the processes involved.’<sup>305</sup> In similar ways, the development of motion control systems in such systems will require ‘the use of nonlinear models’ and ‘neural-net-like learning methods.’<sup>306</sup> In order to achieve higher levels of understanding and productive implementation of morphodynamic design, the developments envisaged in soft robotics are as relevant for architectural design.

## **Prototyping and Construction**

Irrespective of simulations or theoretical analysis, all design efforts associated with the notion of embodiment must converge towards the physical. Prototyping and construction are fundamentally important testing vehicles, and feedback can help improve experimental set-ups or provide new insight altogether. This is the area where soft robotics and architectural design already share some strategies and methods, especially in the use of 3D printing and robotic fabrication technologies. Contemporary architectural research such as

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<sup>304</sup> Sheperd et al. 2011, 4. Shepherd et al. point to various strands of research into the material capacities, non-linear modelling of soft, elastomeric materials and computational control with AI. See: Gent A.N. ‘A new constitutive relation for rubber’ in *Rubber Chem Technol.* 1996. vol 69. pp 59-61; Efe M.O. and Kaynak O. ‘Stabilizing and robustifying the learning mechanisms of artificial neural networks in control engineering applications’ in *Int J Intell Syst.* 2000. vol 15. pp 365-388.

<sup>305</sup> Trivedi 2008, 112.

<sup>306</sup> Sheperd et al. 2011, 27-29 and 30-31.

Tom Wiscombe's 'composite thinking'<sup>307</sup> or Neri Oxman's 'material ecology'<sup>308</sup> question conventional 20<sup>th</sup> century assembly logic in favour of systematically and materially integrated approaches. Demonstrating a strategy shift, not only in manufacturing possibilities but also design sensibility this approach anticipates a artefactual trajectory towards material programmability and adaptability. Currently commercially available platforms such as Stratasys TangoPlus are capable of 3D printing both rigid and rubber-like materials together within the same structure.<sup>309</sup> Although there are limits in flexibility and construction, the technology already promises the possibility of directly printing complex morphodynamic systems.<sup>310</sup> By cutting out the moulding stage this technology can speed up model-prototype evaluations and provide a platform for designing material itself,<sup>311</sup> as currently researched, for instance, in Neri Oxman's MIT Mediated Matter Group.<sup>312</sup> In an embodied design space, adjusting materials to a particular morphology implies material differentiation, as it implies that the material dynamics are uploaded into a self-model. When designing the embodied, it does not matter, it appears, where you start.

## c7 | Conclusion

Embodied design strategies emerging from speculations and experiments with morphodynamic space-making are anticipating the dissolution of traditional heterogeneities of architecture that tend to divide buildings into structures of technology (exterior) and the mechanics of the biological (interior). Beyond inert strictures of tectonic strategies, morphodynamic primitives (envelopes, stueps, edges) undulate, shift, warp or transform while others generated through these motions appear and disappear (apertures, folds, thresholds). But ultimately such spatial contortions have to be controlled in order to

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<sup>307</sup> [http://tomwiscombe.com/project\\_007.html](http://tomwiscombe.com/project_007.html); accessed 2013/09/27.

<sup>308</sup> Oxman 2011 and in Menges 2012.

<sup>309</sup> For printers and material specification see <http://www.stratasys.com/materials/material-safety-data-sheets/polyjet/rubber-like-materials>; accessed 2013/08/24.

<sup>310</sup> Currently limits lie with the flexibility of the soft material, which is acrylic based and has a very low flexibility coefficient. Other limitations are the requirement of support material that is used during the printing process. The material is required to support cavities and needs to be removed after completion of the printing process, which is unfeasible with pneumorphs due to their closed structure.

<sup>311</sup> Armstrong, Rachel. 'Designer Materials for Architecture' in Cruz 2008, 86-89.

<sup>312</sup> Oxman 2011.

provide a safe and compliant environment for human beings. Recent developments in soft actuation technologies and soft robotics are providing speculative platforms and potentially enabling technologies that will eventually exert influence on how architecture can safely and meaningfully adapt, respond or interact with human beings, eventually shifting towards more anthropo/bio/eco/logically compliant modalities.

When Negroponte recognized – but could not resolve – the philosophical schisms between intelligence and robots, he noted that his inkling was that ‘soft materials and cellular pneumatics [are] the most natural materials’<sup>313</sup> to reconcile the schism. Negroponte’s question, ‘[c]an a machine learn without a body?’<sup>314</sup> already alluded to the notion that intelligence can only emerge in complex bodies that are soft in order to facilitate their motility. This subsequently led to the assertion that concepts of ‘hard architecture’<sup>315</sup> are unsuitable for the contemplation of seamless interaction between humans and architecture. The embodied architecture approach is fundamentally driven by the assumption that the machine continuum – and in consequence the technological continuum – will develop towards more integrated, anthropologic, co-constituting and embodied conditions, presenting the opportunity to inspire architecture through reciprocal conditioning of its constituent systems, materials, morphologies and behaviours. But rather than a data-driven, body-less design space, design speculations can be incorporated into design space through emphatic transfers projecting the corporeal basis of human being into an architecture that feels. Conceiving of such architectural environments in the sense of embodiment imposes challenges on architectural design that are more likely to be overcome through empathy rather than through reductive or optimisation strategies. Conceiving of architecture as sensitive and self-aware, capable of acting providently, and considerate through a ‘body’ implies that architects must ask themselves: ‘How would it feel to be architecture?’ Instead of designing architecture from the outside, architects must become architecture. How would it feel to be inhabited?<sup>316</sup>

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<sup>313</sup> Negroponte 1975, preface p. ix.

<sup>314</sup> Negroponte 1975, 151.

<sup>315</sup> Negroponte 1975, 154.

<sup>316</sup> The understanding of ‘being inhabited’ also suggests analogies to the experience of mothers carrying their child. The human residency in the womb has given rise to reading enclosed spaces and especially architecture in analogous manners. See for instance Peter Sloterdijk’s *noo-sphere/ egg* and *uterus* theories, where he reflects on some mythical and evolutionary conditions associated with the womb (Sloterdijk 2011 [1998] and ‘Schaueme’ essay in *Arch+*. Issue 169. 2004).

Like all empathic endeavours, exchanges between human designers and their embodied designs are also bound by a fundamental difficulty and desire for accessing subjective experiences, sensualities and intuitions of beings that have bodies other than ours.



# Conclusion

Research findings – Implication of research – Further areas of research – New proximities between architects and machines

When I have put forward speculations about the architectural potential of soft machines, I have been inspired by an understanding of machines as an architectural medium that is material and dynamic in as much as it is social and spatial through the conditions and connections it creates. While appreciating the ‘hard’ mechanical past of architectural machines I have shown that the longstanding alliance of machines and architecture has converged towards softer modalities including computational practices, bio-inspired design sensibilities and new material technologies, enabling the soft machine to co-constitutionally mediate material properties, performative design, environmental influences and structural behaviour with human desires, habits, rites and idiosyncrasies. In this respect, I wish to reiterate in concluding this thesis that what constitutes a soft machine should not be considered independent from, but rather a consequence of, social, biological and spatial structures. This thinking advocates the view that a soft machine is primarily understood in the way how it establishes relationships, how it makes use of, entangles and promotes structures and technologies. It is not one technologically autonomous soft machine, or body, but the power of their humanely combined enunciations that constitute their heterogeneous nature.

It is in this sense that I have proposed the soft machine as a medium that may engender new forms of subjectivity, experience and enquiry and become an integral participant in architectural design spaces encouraging inclusive and co-constituting modalities of thought.

## Research findings

My attempts to better understand the interstitial space between bodies and machines by creation of a hybrid led to installing the soft machine as an experimental medium, absorbing influences from both sides to inform speculative designs and theoretical reflections alike.

### *Machines beyond mechanics*

As a continuum of architecture, the machine has influenced the history and tradition of the discipline. For many twentieth century architectural theorists and practitioners, including László Moholy-Nagy, Tatlin, Le Corbusier, Giedion, Kiesler, Mumford, Banham, Tzonis, Lefaivre, Denari, Libeskind and many others, the machine was fundamental to advancement in architecture. But before architecture could embrace the machine as design medium developments such as Newton's mechanics established the intellectual pre-conditions that enabled mechanisation to become a crucial component of conceptual architectural thinking. The idealised autonomy and deterministic behaviour of mechanical systems provided the pretext for seeing the machine as symbol of progress and more forward-looking and open-ended approaches to the architectural problem. I found it necessary to write a 'hard' history and theory of architectural machines, not only because I felt that these developments should be accounted for, but also to establish a historical background against which the evolution of soft machines towards more integrated and co-constituting conditions can be assessed.

### *Anthropocentric design sensibility*

Arguing against the mechanical paradigm—which has not only imposed functionalist regimes on architectural design but also affected conceptions of human corporeality—necessitated proposing alternative concepts that are more affine to human and natural conditions. As emerging technologies such as soft robotics suggest the possibility of more equal and co-constituting conditions, they give rise to speculations about the possibility of more seamless relations between human beings and architecture. As a consequence, my research takes steps towards more synaesthetic imaginations of architecture, where architecture is conceived as human-centred environment. However, it is essential to

understand that soft machines are not intended to offer design guidance, nor are they designed to become inhabitable architecture, as Negroponte envisioned the second generation of his soft architectural machines.<sup>1</sup>

The design and appreciation of architecture as if it had a body has always been the flip side of architecture's anthropocentrism. Thinking of the machine in softer terms enables it—and subsequently architecture—to relate to human beings in more meaningful and relational terms. But the commitment to the human does not make the human the exclusive agent. Rather, I wish to reinforce that soft machines are not trying to simulate or replicate human bodies. The design of Greek temples was based on symmetries found in the human body, but form and material was not human. Similarly, soft machines are inspired by capacities and sensitivities of human bodies, but they take shape in non-human forms. The anthropocentric sensibility is inspired by an effort to establish more inclusive conditions between humans and architecture. I believe that the anthropocentric binding of soft machines can be useful in allowing designers to appreciate and deploy the generative powers of the corporeal in designing the envisioned.

### *Softness and the machine*

The soft machine, dwelling on the shrinking threshold between man and artifice, can provide insights into how human behaviour can inform the design space of architecture. The application of a materialist-mechanical conception of 'softness,' as proposed in part 3, into architectural machines provides productive and intuitive strategies for speculations about how architecture can be conceived to allow humans to engage more seamlessly with their immediate surroundings. Thus, the confrontation of the machine with corporeal softness leads to questions about some of architecture's most fundamental paradigms of permanence and immutability. The unbreakable binding of softness and motion embodied in soft machines has brought back human movement and sensitivity as vital way to appreciate and feel architecture. The paradox of architecture softened by machines no longer relates human corporeality and architecture as assemblage of discrete systems, standards and components but as co-constituting and collaborative bodies.

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<sup>1</sup> Negroponte 1975, 5.



### *Pneumorphology and Morphodynamics*

My experimentation with soft machines was driven by the thesis that non-Newtonian mechanical motion induction could provide different and novel ways for enabling movement and transformation in architecture. Based on this thesis I have articulated the activation of softness as design brief for my architectural machines, seeking to research and develop completely soft actuators. However, it was only when I realised that the complete dissolution of frame-actuator/ skeleton-muscle duality would lead to new, more fluent and continuous transformations, that I realised the full potential of hybridised conceptions where structures and actuating components became inseparable. Subsequently, my soft machines became really soft. The elastic nature of elastomer structures inflated by air provided a rich test bed for experimentation with motion induction in entirely soft and elastic structures. Subsequently, I have come to propose Pneumorphology as a theory and experimental framework for structures that are elastic, pneumatically actuated, and dynamically transformable. As shown by discussion of transformable pneumatic precedents, this framework can be understood as the continuation of dynamic and transformable pneumatics where architecture and soft robotics share a typological history of inspirational sources, interests, experiments and inventions in cellular pneumatics. Under the umbrella term morphodynamic transformations I examined in detail how particular spatial transformations may be choreographed involving multiple pneumorphic fields, cavity design and layout, elastomer specification and conditioning and phased actuation, and potentially involving highly dexterous spatial transformations, such as higher degrees of freedom (DOFs), capability of elongation as well as multiple direction bending and spatially distributed stiffness.

### *Soft tectonics*

Soft and pliable interpretations of enclosures or spatial ordering structures critically challenge traditional tectonic denominations of space based on fixed architectural permanence and rigidity typified by static elements such as walls, floors, and ceilings. The many possibilities offered for space-making with pneumorph structures and their morphodynamic transformations gave rise to the necessity for the proposal of a new kind of soft tectonics. The design of spatial primitives such as *epithelial envelopes*, *stuepls*, *edges*, *apertures*, *folds* and *migrating thresholds* does not constitute the design of fixed form but the

design of behaviour that includes corporeal capacities and sensitivities. Constituent of these morphodynamic primitives space can be conceived as intrinsically (com)pliant, transformable, dynamic and passively dynamic leading to possibilities for space-making by means of transformational conceptions of the architectural envelope.

### *The liminal space of stuepling*

The elastic actuations of pneumorphs can facilitate the complete inversion of a surface, such as performed when turning a soft enclosure such as a sock or a pocket inside out. In order to describe this process I have created the neologism *stuepling*. It would be extremely difficult to achieve such transformations involving multi-directional bending, variable stretching and compression, relying solely on mechanical means. Combined with other structures such as composite structural bracing, embedded air conduits, pneumorph fields and embedded fluidic networks, stuepling provides the possibility to create, by means of transformation, many spaces with one morphology.

### *Embodied design*

In the emerging field of soft robotics research into mental development and artificial intelligence suggests that an active and soft body is indispensable for the acquisition of intelligence and self-awareness. The inclusion of softness as constituting and generative agency is considered an essential movement away from the mechanical paradigm towards the embodied.<sup>2</sup> My aim was to learn from these insights and apply new-found design sensibilities to architectural design. Subsequently, I have formulated embodied design as a strategy that envisions architecture as a capacitated, sensitive and sensual body. Embodied design thinking binds humans and non-human elements together, infusing the artefact with the corporeal. The conceptual approach of *designing architecture as if it were a body* becomes central to the integration of systems, materials and behaviours on a system-level-symbiosis.

## Implications of research

Taking the oxymoronic conditions of the soft machine as inspiring point of departure, and insisting on its corporeality, softness and its unbreakable binding with movement and human sensitivity, can inform holistic strategies for instilling autonomy and embodiment in conceptions of architectural space. Conceiving of architecture as non-human performer through the agency of soft machines establishes an anthropocentric mandate that shines onto technologies, methods and strategies explored.

### *Paradigm shifts towards the dynamic, behavioural and autonomous*

In the face of waning enthusiasm for the simulated and the virtual leading practitioners and theorists, such as Chris Slater and Roy Ascott have ascertained a shift in cultural production towards the embodied, the situated and the dynamic.<sup>3</sup> Rather than aiming for the creation of unalterable form, design becomes a competence of understanding complexities and consequences of behaviour and interactions. This approach is inherent to the embodied soft machine design approach and its tendency towards finding solutions by incorporating the dynamic and the corporeal.

### *De-limitation of digital design by a new breed of machines*

By discussing an inherently physical and dynamic medium in times dominated by digital design I did not intend to formulate a rejective critique of the digital. Instead the research allowed me to formulate strategies for more inclusive and co-constituting approaches that entangle digital and analogue modalities of production. The current de-limitation of digital design practice is led by a new breed of machines ranging from simple desktop 3D printers to programmable robotic platforms that enable architects to export their designs into the physical realm. In remarkably similar ways to Negroponte's research into the potential of his soft architecture machines in the 1970s, architects now communicate and work with machines for the advancement of architectural design. Architects look – once again – at machines as appropriate means for resolving architectural problems. I believe

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<sup>2</sup> Pfeifer and Josh 2007; Pfeifer, Lungarella and Iida 2007.

<sup>3</sup> Salter 2010, xxi; Ascott 2000, 6.

that through my research I have achieved to demonstrate that the soft machine can contribute to these developments by entangling human and architectural behaviour, corporeality and sensitivities.

### *Biophile design through corporeal performances*

Architecture's classical default mode 'against nature' is being fundamentally revised by the deployment of bio-affine strategies that range from aesthetic and formal applications (biomorphism, etc.) to systematic and symbiotic ones (morphogenetic design, sustainable and adaptive systems approach).<sup>4,5</sup> As digital design and production begins to engage with the corporeal logic of living systems, architecture—in responding to the corporeal beings that are houses—can take inspiration from the corporeal powers of the living as well.<sup>6</sup> In line with these reflections, I believe, the soft machine is especially suited for experimentation with the following conditions by making them intrinsic to architectural design:

- Systems and structures merge, materials with transitional and tuneable properties will enable integration of adjustable behaviour into material: opaque - transparent, hard - soft, passive - active, hot - cold, sensitive - resistant, etc.
- The ideal of industry-led pre-fabrication gives way to the ideal of on-demand fabrication and synthetic growth.
- Form becomes inclusive of human capacities and sensitivities as well as autonomous behaviour of non-humans (systems, robots).
- The dissolution of behavioural polarities (work - play; private - public; online - offline) will favour non-descript, dynamically transformable and adaptable spaces rather than discrete, mono-descript entities.

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<sup>4</sup> Architectural historian Mallgrave observes, 'the appeal to a higher authority outside the discipline of architecture is not new, but the shift from the post-structuralism of the 1980s in this instance is notable – Darwin has replaced both Derrida and Deleuze' (2011, 165-166).

<sup>5</sup> Salter 2010, 277 + 292.

<sup>6</sup> Palumbo 2000, 6.

## Further areas of research and design

When I have infused softness into the machine I have followed the instructions of their entanglement. Currently my own soft machines, as well as those developed in the wider field of soft robotics, have very high degrees of potential applicability to further research and development due to their speculative nature, and mutual inspiration between creative and empirical methods can take place. Developments in the fields of robotics, material sciences, construction and prototyping signify a shift towards more softer and hybridised modalities. Some of these developments may have significant influence on architectural design speculations.

### *Designing machines as if they had a body*

Ambitions for autonomous behaviour, artificial and embodied intelligence that drive research in robotics are likely to align artificial capacities and sensitivities with those found in natural and human bodies, if not supersede them. Some of the developments signalling disruptions with traditional approaches are emerging from research into ionic engineering. This approach breaks with traditional electronic systems based on electrons in favour of systems composed of soft, stretchable and transparent electronic components and actuated matter. This promises the complete integration of control circuits into elastic components. Applied in architectural terms, this technology can give rise to research into the space-making potential of morphodynamic envelopes combined with transparent screens and windows that can sense and actuate movement.<sup>7</sup> Other developments include remote experiences, kinesthetic teaching and human-robot-interface (HRI),<sup>8</sup> alternative

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<sup>7</sup> Kelpinger et al. 2013. Christoph Kelpinger of Harvard School of Engineering and Applied Science explains that '[t]he big vision is soft machines' ... for '[e]ngineering ionic systems [that] can achieve a lot of functions that our body has: they can sense, they can conduct a signal, and they can actuate movement' (Interview on independent.co.uk, accessed 04/09/2013).

<sup>8</sup> In 2001 Robotic pioneer Rodney Brooks was optimistic 'that the direct neural interface between man and machine is starting to happen' (2001, x). Now, more than ten years later a growing numbers of implants (e.g. cochlear, retinal, cardiac, gastric, etc), prosthetics and wearable digital devices are replacing, extending and enhancing corporeal capacities. Also see Lungarella, Max. Max Lungarella, Fumiya Iida, Josh Bongard, Rolf Pfeifer (ed.) 2007. *50 Years of Artificial Intelligence: essays dedicated to the 50th anniversary of artificial intelligence*. Berlin: Springer.

soft actuation technologies such as jamming,<sup>9</sup> evolutionary computing, automatic design<sup>10</sup> and fabrication technologies using adjustable digital materials.<sup>11</sup> What all these research efforts have in common is that they are driven by design thinking based on a new framework that links the natural and artificial domains by conceiving of the artefact as corporeal, dynamic, sometimes self-aware entity. Due to its inherent physicality and corporeal conception the soft machine can enable architectural design to appreciate and unfold the potential of these technologies onto architectural design.

### *Sensuality of the synthetic*

The emancipation and subsequent simulation of human sentiment through the agency of the machine has a long tradition.<sup>12</sup> As mentioned in the introduction by example of Cornelius Drebbel's incubator and Mme du Coudray's birthing machine, the role of softness in the anticipation of natural capacities and behaviour through machines could lead to a better understanding of the sensuality we associate with machines that seem to be alive, or that resemble living processes or behaviours. Jessica Riskin refers to robotic pioneer Rodney Brooks' conviction that artificial intelligence and feelings have to be 'physically grounded' and 'embodied,' to highlight remarkable similarities with the eighteenth century conviction that life, consciousness and autonomy are embodied in animal and human machinery.<sup>13</sup> Riskin maintains that already Mme du Coudray's birthing machine reflected the assumption that 'an artificial model of a living creature should be soft, flexible, sometimes also wet and messy, and in these ways resemble its organic

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<sup>9</sup> Jamming is a new class of soft, flexible, mesoscale objects that can change in shape and rigidity by compression of granular material inside elastic bodies. See Steltz, Erik. Mozeika, Annan. Rembisz, Justine. Corson, Nick and Jaeger, Heinrich. 'Jamming as an Enabling Technology for Soft Robotics' in Proc. *SPIE 7642, Electroactive Polymer Actuators and Devices (EAPAD)*. 2010. 764225. doi:10.1117/12.853182.

<sup>10</sup> Cheney, Nick. MacCurdy, Robert. Clune, Jeff. Lipson, Hod. 'Unshackling Evolution: Evolving Soft Robots with Multiple Materials and a Powerful Generative Encoding' in *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO)*. 2013. pp 167-174.

<sup>11</sup> Stratasys, one of the leading manufacturers of 3D printers and materials for personal use, prototyping, and production, announced in January 2014 a multi-colour, multi-material 3D printer that can produce parts with virtually unlimited combinations of rigid, flexible, as well as color digital materials - all in a single print run.

<sup>12</sup> Jessica Riskin locates the beginning of this tradition in the seventeenth century when Enlightenment philosophers and engineers started to test the boundaries between life and mechanism (2007, 239).

<sup>13</sup> Brooks 1990; 1991.

subjects.’<sup>14</sup> Contemporary efforts in robotics to create ‘sameness of living and artificial machinery’<sup>15</sup> suggest that the fundamental typological distinction between us and not-us, that has so far framed the way we think about and re-present the material world<sup>16</sup> is going to be dissolved by infusion of human capacities into artificial machines and systems. More than its sibling methods of architecture, such as the drawing, model, text, image or algorithm, the soft machine carries the potential to be (intentionally or not) zoo/botano/anthropologised through insistence on its corporeal reality, thus offering itself for inquiring sensual nature of machines and their enunciative powers.

### **New proximities between architects and machines**

Relations between architecture and technology vary and change, but when embedded in the steady flow of history, technology has always influenced how architects envision, evaluate, communicate and realise their designs. I have discussed soft machines in this thesis knowing that, beyond their technological capacities and structuration, they carry enunciative powers. The capacities, sensibilities and sympathies that we instil and rediscover in these types of machines can yield novel ways for studying the human condition in relation to architecture. It is my hope that research with soft machines can enable designers to better understand the co-constituting and entangled conditions that they create when constructing an artificial realm that ultimately shares its corporeality with ours.

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<sup>14</sup> Riskin 2007, 258.

<sup>15</sup> Riskin 2007, 263.

<sup>16</sup> Franck 1994, 41 [*italics in original*].

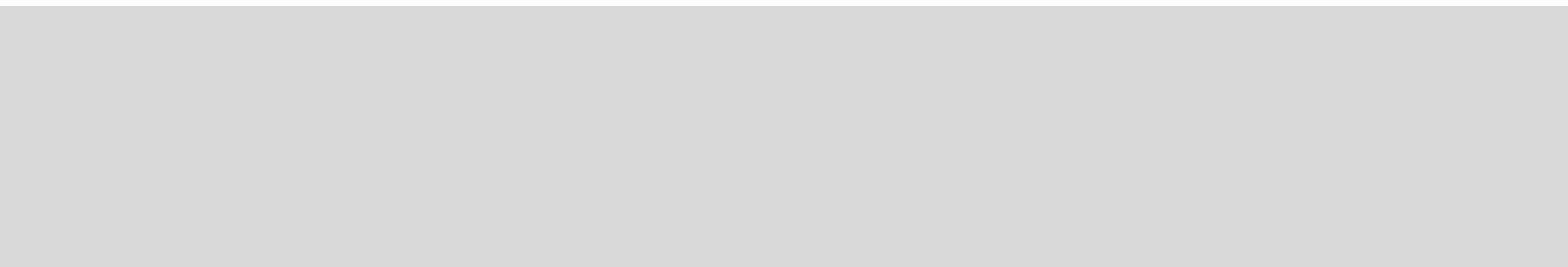






# Appendices

## Bibliography





# Appendix 1 | Construction methods

In this section I offer a brief introduction to selected methods and processes for the construction of soft components. Specific aspects of working with many synthetic soft materials such as polyurethane rubber, latex, silicone or photopolymer prototyping are related to the way in which these materials acquire their form. One aspect of particular importance when working with soft materials is that the majority of them undergo phase changes from liquid to rigid or soft. The phase change is induced either by catalysing agents, through cooling, solvent / liquid evaporation or exposure to UV radiation. These processes have to be taken into consideration at the design stage. What follows is a discussion of some selected techniques for the construction of component parts of soft machines.

## *Bladder making process*

This process is a variation of the skinning technique where foam is used as positive mould. The flexible nature of the positive mould allows for uncomplicated de-moulding. But when the desired form is topologically closed the skin has to be cut and rejoined. In the case of the bladders of the Bladder Puppets this problem was addressed by installing a zip (fig a1.01).



fig a1.01 Bladders of *Bladder Puppets* with zips. 2010.

## *Bulging*

Bulging is a form of casting in which the piece is poured without formwork. Exposed to its own flow characteristics, the sculpture gains its structural integrity only when material is poured and the material gradually sets due to catalysing or cooling down. This process exploits the material's inherent phase-changing properties; in the case of bulging its transformation from a liquid state into a stable, but nevertheless soft, phase state. In the case of Louise Bourgeois' *Soft Landscapes* rubber was 'exploited as a kind of anti-sculptural material – soft, impermanent, and deformational' as Nixon has described it.<sup>17</sup> This method has also been used by other artists, including Danish designer Gunnar Aagaard Andresen and American artist Roxy Paine. In their work these artists exploited the phase transition that soft materials such as rubber and latex undergo when curing. The aesthetic of liquids when solidifying in the process of pouring leads to the 'bulging' aesthetics.



fig a1.02 Roxy Paine. *Sumak*. 2001.



fig a1.03 Louise Bourgeois. *Soft Landscape II*. 1967.

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<sup>17</sup> Nixon, Mignon. 1999. 'Eating Words', p 59; where he also refers to the use of latex as 'anti-sculptural material' in reference to Eva Hesse's work (ibid., p.62).

In my own work I experimented with slow flowing capacities of bitumen. The *Transient Proximities between a Pitch Chicken and a Hairy Microphone* (2005) project experimented with ideas of a slow architectural environment. In order to induce minute changes over a long period of time, I chose a material that flows slowly under the gravitational pull. Bitumen, also known as asphalt or pitch, exhibits a type of viscosity that is similar to that of cold molasses.<sup>18</sup> In this project bitumen has been applied to a scaffold, in this case a skeleton of a chicken, and a lump of hairs (my own) fitted to a metal pole. In comparison to the flow rate of bitumen, hair grows extremely quickly. In this project, I brought two independent objects into symbolic proximity with each other in order to create space that is metaphorically changed by two material velocities.

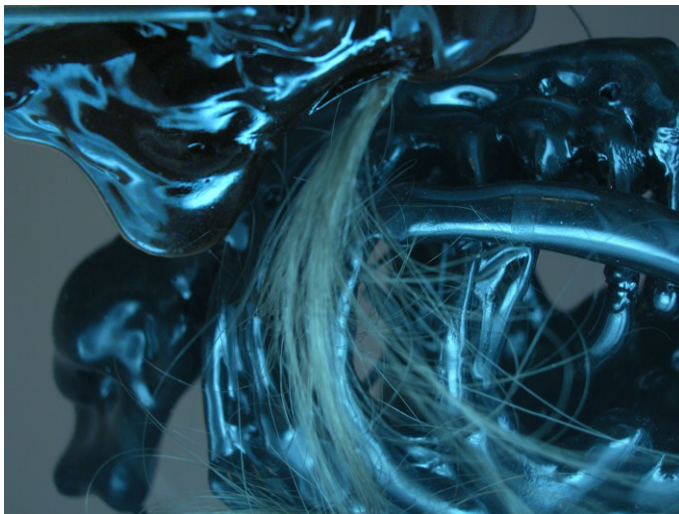


fig a1.04 Transient proximities between a pitch chicken and a hairy microphone. 2005.

A chicken skeleton and a lump of hair covered with bitumen in order to contrast two material velocities.

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<sup>18</sup> The use of bitumen is inspired by the 'Pitch Drop Experiment' initiated in 1927 by Professor Thomas Parnell of the University of Queensland in Brisbane, Australia, to demonstrate to students that some substances that appear to be solid are in fact very-high-viscosity fluids. The experiment measures the flow rate of the substance and is still ongoing. The falling of the ninth drop was imminently expected in 2012 or 2013. The eighth drop fell on 28 November 2000, allowing experimenters to calculate that the pitch has a viscosity approximately 230 billion ( $2.3 \times 10^{11}$ ) times that of water. See <http://www.smp.uq.edu.au/content/pitch-drop-experiment>, accessed 09/10/2012.

## *Casting*

When constructing components made out of soft materials, a construction process often involved is casting. Casting is ideally suited for prototype making.



fig a1.06 Casting of *Shoe for Justine & Juliette for walking in Slow Architecture*. 2007.  
Chavant model and Polymer rubber cast and mould of internal harness.

The beauty of many casting techniques lies in the combination of material properties with the appropriate casting method (e.g. bronze casting is in equal parts metallurgy and art).<sup>19</sup> Virtually all material properties, such as elasticity, Shore hardness, tear strength etc. can be modulated by choice of material, additives, mixing ration and casting method. The casting process normally involves mould making around an original model.<sup>20</sup> When the original model is taken out of the mould, the material can be poured into the cavity where it solidifies. Traditional mould making and casting methods can be combined with other prototyping methods such as rapid prototyping.

## *Digital downstream processing and prototyping*

When the casting process is combined with rapid prototyping techniques such as selective laser sintering (SLS), stereolithography (SLA), CNC milling etc., the mould can be modelled digitally and used as a master mould for downstream processing. If nylon or

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<sup>19</sup> In artistic use, bronze sculptures are often cast lost-wax casting process where a positive is sculpted in wax, which is then packed in with sand. The mould is then heated and the liquid wax runs out of the mould. The mould can then be filled with any kind of suitable material but can only be used once as it is destroyed upon the process of un-moulding the sculpture.

<sup>20</sup> Generally moulds are made of silicone, plaster, Jesmonite®, glass fibre reinforced or epoxy resin. The cheaper alternative to epoxy resin, polyester resin, is not recommended as it contains carcinogenic chemicals such as styrol.

plaster-based materials are used the mould has to be sealed or strengthened with adequate materials such as wax, shellac, cyanoacrylate (super glue) or epoxy resin for reproduction of the model in a desired soft material. If sealers are undesirable for further use of the casting pattern, such as in pneumorphs [c7.s2 Pneumorphology + s3 Morphodynamic transformations and space-making] the moulds can be printed with photopolymer printing.

### *Photopolymer printing*

This process is very effective for component making for soft machines. The moulds for my projects *Nemone stuehp* (2013) and *Robe* (2013) have been built with *VeroClear* on the *Objet Connex 500* printers at the Digital Manufacturing Centre (DMC) at the Bartlett School of Architecture, UCL. This choice of printing methodology and material ensured the necessary quality and release performance of silicone cast. The process also enables printing soft and varied-shore hardness components. The potential of advanced polymer composite manufacturing has been demonstrated by MIT based architect and digital fabrication researcher Neri Oxman in some of her projects.<sup>21</sup> Although these projects are not exploiting their inherent soft mechanical properties they are nevertheless presented here in order to demonstrate the potential of this technique. *Cartesian Wax* (2008) is continuous tiling system composed of ultralow –viscosity urethane rubber and semi-rigid polyurethane resin composite components.<sup>22</sup> *Monocoque* (2010) involves the heterogonous combination of load bearing structure and non-bearing skin. The object is a structural skin that is generated using a Voronoi pattern that corresponds to an assumed design load. The prototype model was stereolithographically printed with photopolymers.<sup>23</sup> This

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<sup>21</sup> For early research output and interview see Neri Oxman in *Matter* magazine <http://www.materialconnexion.com/Home/Matter/MATTERMagazine/MATTERInterviewNeriOxman/tabid/699/Default.aspx>, accessed 23/10/2010.

<sup>22</sup> Brownell 2010, 225.

<sup>23</sup> Jetted photopolymer is an additive process that combines the techniques used in Inkjet printing and stereolithography. With this method each layer is built up by depositing tiny drops of build material and support material to form each layer of a part. The build material is a liquid acrylate-based photopolymer that is cured by a UV lamp after each layer is deposited. For this reason, jetted photopolymer is sometimes referred to as photopolymer InkJet printing. Two companies that have developed jetted photopolymer devices include Objet Ltd. and 3D Systems. For additional information see <http://www.custompartnet.com/wu/jetted-photopolymer>, accessed 12/11/2012.



technology allows for the assignment of structural properties (elasticity, Shore hardness) to various three-dimensional substances, printing interrelated parts in a single build, as well as creating composite materials with preset mechanical properties.<sup>24</sup> For further literature on 3D printing and prototyping see Bártolo et al. 2012.

### *Skinning, skin-moulds*

Skinning is a process where liquid such as latex or silicon rubber is applied in layers to a positive mould and the 'skin' is released upon curing. This technique can be used on all non-porous materials or with adequate sealer. The material's viscosity needs to be adjusted with thixo-additives in order to control wall thickness and texture.<sup>25</sup> Higher viscosity materials can be worked as slurry coat that is applied by throwing the material onto the positive with a trowel or spatula. When porous materials such as polyurethane foam is used and left unsealed the cast acquires the negative texture of the foam, which when turned inside out is a surface with many little positive globuli. When sealed with silicon the cast acquires the texture of the silicon which can be imprinted with various textures in its gelling phase.

### *Lost wax casting*

Lost wax casting is a traditional casting technique where the pattern is made from wax. It is placed in a mould, which is then heated in order to remove the wax, creating a cavity that can be filled with the desired material. This technique can be adopted for the construction of cavities in pneumorphs, such as discussed in c6. s2 Pneumorphology.

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<sup>24</sup> Brownell 2010, 234.

<sup>25</sup> Thixo-additives, or thixotropes are chemicals that change the material solution from liquid to non-slump. When added the mixture can be applied as 'skin' to vertical and overhanging or undercutting objects.

## Appendix 2 | Material glossary

This glossary provides an overview of selected natural and synthetic materials useful for working with soft materials. Some materials are not ‘soft’ per se but they are useful for creating soft material components, for example, when creating moulds for casting. The glossary is informed by my own experimental design and construction of soft machines. Many aspects of materials such as behaviour under stress, or softness or roughness of surface can be described in scientific terms, but the ‘feel’ of soft materials can only be experienced ‘hands-on.’ For information on digital downstream processes, digital prototyping and photopolymer printing used for the construction of the really soft machine projects *Nemone Stuehl!* (2013) and *Robe* (2013) see appendix 2. For a general introduction to material technology, techniques, methodologies and terminologies some literature recommendations are given below.

Recommended literature includes Blaine Brownell’s *Transmaterial* (2005-10) catalogue series where materials are explained according to the way these materials can extend architectural, artistic and industrial applications. Michelle Addington and Daniel Schodek’s *Smart Materials and Technologies in Architecture* (2004) provides a useful introduction to the way external influences determine electrical, thermal, chemical or optical properties. There is a good theoretical and physical explanation of materials in the appendix of Ezio Manzini’s *The Material of Innovation* (1989). Material knowledge and techniques suitable for the construction of soft machines such as modelling, making moulds, casting and model making can be adapted from techniques and methodologies used by theatrical and film prop makers. Recommended literature includes Andy Wilson’s *Making Stage Props* (2003), Keith Orton’s *Model Making for the Stage* (2004) and Jacquie Govier’s *Create Your Own Stage Props* (1989). Excellent guidance for materials, techniques and processes for sculptural use is given in Oliver Andrews’ *Living Materials* (1983) and Nick Brooks’ *Mouldmaking and Casting* (2005) and *Advanced Mouldmaking and Casting* (2011). Selected online sources of information with catalogues, technical support, product information and tutorials include [www.flints.co.uk](http://www.flints.co.uk), [www.sculpt.com](http://www.sculpt.com) and [www.smooth-on.com](http://www.smooth-on.com).

### *Alginate*

Very useful for quick studies where a flexible mould is required. The fine powder is mixed with water for a quick-setting compound. The mould retains moisture which might inhibit some casting materials.

### *Chavant clay*

This material is an oil-based sculpting compound. Like plasticine it is non-drying and can be reworked. When molten the clay can be poured. Similar to epoxy putty, the surface can be locally treated with water to smoothen it.

### *Clay*

This natural material remains very important for sculpting because of its excellent working properties. It is a low cost material that can be reused. However, it is not suitable for making very small objects, or to create fine detail, as it dries out very quickly. Reinforcing armatures made out of metal wire or wood provide rigidity to the sculpture and are especially necessary for larger works. Unless clay is fired to produce a ceramic object, it needs to be kept wet by wrapping in wet cloth or plastic film, otherwise it will shrink and crack. Like Chavant and wax, the material should be thought of as a vital intermediary for making originals to be cast in more durable materials.

### *Electrically and mechanically self-healing composite with pressure- and flexion-sensitive properties*

This material is flexible and electrically conductive. It can sense mechanical forces and yet it is able to self-heal repeatedly. This can be of use in emerging fields such as soft robotics and biomimetic prostheses. It is a composite material composed of a supramolecular organic polymer with embedded nickel nanostructured microparticles, which shows mechanical and electrical self-healing properties in ambient conditions.<sup>26</sup>

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<sup>26</sup> See paper by Benjamin C-K. Tee, Chao Wang, Ranulfo Allen and Zhenan Bao in <http://www.nature.com/nnano/journal/vaop/ncurrent/full/nnano.2012.192.html>, accessed 13/11/2012.

### *Epoxy putty*

The material is normally available as two-part compound in sticks that are mixed in a 1:1 ratio. A popular trade name is Milliput. The mixture is soft and malleable before setting to an extremely hard and strong material within a few hours. Warmth increases softness and accelerates setting time, cooling does the opposite. When used for modelling the surface can be locally treated with water to smoothen it.

### *Gut string*

Gut strings can be used instead of metal cables where a more organic look is preferred. They are made from animal intestines. Traditionally tennis racquets and musical instruments used gut string.

### *Felt*

Sheep wool felt is produced by the 'wet felting' process through which the fibres are interlocked to a non-woven mat. Variable stiffness can be provided by treating the felt with natural additives such as rabbit-skin glue. Felt is used widely in clothing, building and automotive industries. Felt is ideally suited for prototyping as its density, shape, texture and colour can be adjusted seamlessly through choice of production methods and additives.

### *Formerol®*

Another very interesting type of silicon is a product called Formerol®. This is a new class of silicone material that can be moulded and cured at room temperature, is UV resistant and electrically insulating. Additionally, Formerol® has excellent adhesive properties and can be fitted to most substrates for insert-molding or customised grip moulding.

### *Hot-melt vinyls*

These materials become liquid when heated and can be poured over an original to make a mould. Old moulds can be melted down and reused. The vinyl has a self-skinning property, which results in a greasy surface, but the original still needs treatment with a release agent when casting with tenacious materials such as urethanes or epoxy resins.

### *Latex*

Natural latex is found in the plant world as a milky fluid that can be extracted from lactifying plants. The plants exude the liquid, which then coagulates on exposure to air. Latex protects the plant from herbivores. The liquid is the stable dispersion (emulsion) of polymer microparticles in an aqueous medium. When processed it can be used to produce many materials, amongst which the most important is natural rubber.

### *Natural rubber*

This material, sometimes also called India Rubber or Caoutchouc is classified as an elastomer (an elastic polymer). It is derived from latex from the Pará rubber tree (*Hevea brasiliensis*), and is used in products such as latex gloves, latex condoms and latex clothing.. Natural rubber is normally very stretchy and flexible and extremely waterproof, and exhibits unique physical and chemical properties.<sup>27</sup> There are two main solvents for rubber: turpentine and naphtha (petroleum). Unfortunately, it has very poor resistance to UV and tends to turn dark orange and brittle when untreated. Several substances can be added to alter the workability of the material, such as thixotropes and colours.

### *Plaster of Paris (or gypsum plaster)*

This type of plaster is produced by heating gypsum to about 150 degree Celsius. The name has historically derived from plaster produced from a large gypsum deposit at Montmartre in Paris. This material is used for mould making as well as for casting. The classical set up is a rigid plaster mould being formed around a soft original clay model. Plaster of Paris is the more suitable type over traditional building plaster as it becomes very hard and sets quickly. Plasterer's scrim (jute scrim) is used as reinforcement. The advantages of using plaster are versatility, low price and availability, but products made from plaster are heavy and fragile.

### *Polymer-based plaster, Jesmonite®*

Polymer-based plasters are mixed with a polymer solution instead of water. The resulting compound is very strong and tough. It can be reinforced with a specially coated glass-

fibre mesh. As such the composite is a very useful alternative to traditional GRP (Glass Reinforced Plastic) that predominantly use polyester, which is toxic. Although it has none of its flexibility or strength-to-weight ratio, the advantages of polymer-based plaster are that it is non-toxic, has no hazardous fumes and the tools can be washed with water. The ingredients are available as complete system; a typical trade name is Jesmonite®. The liquid part can be bought alone and mixed with 'alpha gypsum' plaster, which is a cheaper alternative to the Jesmonite plaster. Polymer plaster, like Plaster of Paris, can be thinned with trisodium citrate (or citrus juice) or thickened with colloidal silica. It may be coloured with dry pigments. When used as a modelling material, the use of talc prevents stickiness and helps produce smooth and shiny surfaces.

### *Polymer clay*

The material is a soft and pliable sculpting compound until hardened when heated to 130 degrees Celsius. After cooling, the chip- and shatter-resistant material can be drilled, sanded, carved and painted. The material is commercially available in soft and firm compounds. Trade names include Sculpey, Fimo and Cernit. Ideally suited for direct modelling of smaller objects.

### *Polyurethane polymers and rubbers*

Polyurethane polymers (PU) are used in a great variety of applications including flexible, high-resilience foam seating, seals and gaskets, high performance adhesives and foams (for insulation etc.), surface coatings and sealants, and synthetic fibers (including Spandex fibre commonly used in body-tight sportswear). This material is normally cast as a 1:1 component mix. The visco-elasticity of the fully cured material can range from solid to very soft, almost gel-like consistencies. Because of the 1:1 mixing ratio PUs are easier to handle than silicone, but are not self-releasing and exhibit rather aggressive adhesion. Therefore the moulds need very careful treatment.

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<sup>27</sup> Rubber's stress-strain behaviour exhibits the Mullins effect, the Payne effect, and is often modelled as hyperelastic. Rubber strain crystallizes.

### *Polyurethane foam*

Expanded polyurethane foam can be used to cast soft foam objects. This type of foam is normally mixed from two parts. Some mixtures expand during the curing process and some mixtures are self-skinning while others are not. In addition there are open cell foams and closed cell foams, the difference between them being that open-cell foams absorb liquid, while closed foams don't. Most foams, when cured, can be finished with an elastic elastomere based varnish in order to make it more durable as foams are not UV resistant.

### *Silicone*

Silicone rubber is a synthetic material that is inert and can be used in a variety of forms thanks to its wide range of material properties. Silicone is widely used for prototyping, for both the mould and the actual prototype. Typically silicones are available in liquid form. When mixed with a catalyst the liquid cures to a flexible material. Generally I have used condensation and addition cure RTV silicones for the pneumorphs and hydromorphs.<sup>28</sup> Additives may be used to change viscosity, colour or to accelerate curing time. The product is available in a wide range of hardness, colour and translucency. Notable advantages of silicone over other elastic materials such as rubber or latex are its chemical and UV stability, water resistance, durability and low toxicity. Material properties can be adjusted within a wide range by admixtures. These include elasticity, softness, tear strength, vapour resistance, translucency, colour and thermostability. Chemically, silicone is synthesised through chemical processing of silica (silicon dioxide), common in sandstone, beach sand, and similar natural materials—the same materials that are used in producing glass. More precisely called polysiloxanes, silicones are mixed inorganic-organic polymers. The material is very sensitive to mixing ratio, so this is best done with a precise scale. The material, once cured, is self-releasing, which means that it can be cast or moulded with almost every other material without release agents.

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<sup>28</sup> Condensation curing silicone cures with the addition of a liquid catalyst. Addition curing silicone cures with the mixing of two components in a specific ratio, mostly 1:1. RTV stands for Room Temperature Vulcanizing.

### *Swell gel*

Swell gel is the common term for dry, free flowing crystalline granules which are insoluble in water but are able to absorb up to 400 times their own weight in water by swelling. The granules are commonly used for water storage in commercial plant growers and nurseries, and are also used in diapers. Chemically known as polyacrylamide polymer crystals, shape-changing gels or crystals can swell up to several hundred times their volume when in contact with water (Addington and Schodek 2005, 95). The potential of shape transitions induced on molecular levels is very alluring for the imagination of objects able to transform to non-Newtonian laws of physics.

### *Wax*

Waxes are available in a wide range of hardness, colour and melting points and can be used in a variety of applications. Like Chavant, wax takes great detail when used for sculpting, particularly when the tool itself is heated. Wax becomes totally liquid when heated past a certain point, but at lower temperatures wax remains malleable. Wax can be used as a release agent or it can also be used for casting intermediary forms, e.g. lost-wax casting process.

### *Wonderflex®*

A thermoplast composite with a fabric layer that – true to its name – becomes soft and flexible when heated to approximately 60 degrees Celsius. Upon cooling the material becomes rigid again. Wonderflex® is commercially available in sheets and can be formed in virtually any shape in its intermediary phase. The process is repeatable, which allows readjustments to the form. Additionally the material can be laminated when heated offering an extraordinary array of possibilities ranging from fast negative form making for moulding to composite constructions.





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